S
628.53
H2sa
1979

SOME ECONOMIC ASPECTS OF AIR POLLUTION IN MONTANA

STATE DOCUMENTS COLLECTION

MAR 2 8 1980

MONTANA STATE LIBRARY
930 E Lyndale Ave.
Helena, Montana 59601

PLEASE RETURN

TED OTIS
JOHN DUFFIELD
DEPARTMENT OF ECONOMICS
UNIVERSITY OF MONTANA

AND

MIKE RUBY
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF WASHINGTON

NOVEMBER, 1979

AIR QUALITY BUREAU
MONTANA DEPARTMENT OF HEALTH
AND ENVIRONMENTAL SCIENCES
HELENA, MONTANA

MSL
JUN 24 1987
OCT 9 1991

SOME ECONOMIC ASPECTS OF AIR POLLUTION IN MONTANA

Ted Otis
John Duffield
Department of Economics
University of Montana

and

Mike Ruby
Department of Civil Engineering
University of Washington

November, 1979

AIR QUALITY BUREAU
Montana Department of Health
and Environmental Sciences
Helena, Montana

CENEX Petroleum Refinery - The CENEX Petroleum Refinery in Laurel is the third largest contributor to ambient sulfur dioxide in Montana. Despite having the lowest production capacity of the three Billings area refineries, use of high sulfur Wyoming crude makes CENEX the largest contributor to ambient sulfur dioxide in the Yellowstone Valley.

Several sulfur dioxide control options are available to CENEX. It has recently agreed to make numerous modifications to process equipment in order to comply with the 80 ug/m^3 standard. These changes are expected to reduce sulfur dioxide emissions by about 25 to 30 percent. Two new stacks also will be built to improve the mixing of the plume with the surrounding air. CENEX estimates the cost of these already scheduled modifications to be approximately $5 million. If it is necessary to raise the height of an additional four stacks to meet the 50 ug/m^3 standard this would cost approximately $1 million.

As with the Anaconda Copper Smelter, the short-term standards are limiting for CENEX. Compliance with the NAAQS three-hour standard may require both the process equipment modifications and the increased stack heights. An additional option available is fuel oil desulfurization. The costs of this technique is estimated by CENEX to be $80 million. Other less expensive controls no doubt would be considered first.

In light of the expected sulfur dioxide control resulting from the present control program, compliance with the 50 ug/m^3 standard is estimated to cost $5 million to $6 million. CENEX estimates there will be a $500,000 annual operating cost.

result in an annual average sulfur dioxide level below 50 ug/m^3.

To achieve 86 percent control, the next acid plant would have to be approximately 60 percent larger than the present acid plant. (The two plants would operate in parallel.) The capital cost of the new plant and the necessary duct work and stack would be approximately $21 million.

The market for sulfuric acid is very limited in Montana and neighboring states. Anaconda already has found it necessary to ship its acid product into the midwest. The present cost of rail freight to the Chicago markets is approximately $23 per ton. Additional costs associated with shipping are approximately $7 per ton. At present prices this results in very little netback to Anaconda. However, the costs of neutralization of the acid are so substantial that Anaconda could be expected to accept a significant loss on the sales before neutralization would be attempted. Thus, an annual operating cost of less than $1 million could be expected for any reasonable estimate of the market price of acid. If the price Anaconda can obtain for its acid increases faster than rail costs (as some analysts expect) the company could defray some or all of the operating costs.

Other control processes are available that convert the sulfur dioxide into elemental sulfur, liquid sulfur dioxide, or even fertilizer. In general, the initial capital cost is greater but sales of the by-products may permit the control facility to pay for itself. The recently announced Peck-Pircon process is an example of such a device.

Table 15

Major Sulfur Dioxide Emitting Industries in Montana

Industrial Point Source	Area	Sulfur dioxide emissions (tons/years)*
Anaconda Copper Smelter	Anaconda	281,750
CENEX Petroleum Refinery	Billings	10,380
Corette Power Plant	Billings	9,986
Exxon Petroleum Refinery	Billings	9,800
Conoco Petroleum Refinery	Billings	3,198
Montana Sulphur and Chemical Company	Billings	1,530
ASARCO Lead Smelter	Helena	14,000

* Obtained from Gelhaus et al. (1978).

Analysis of Point Sources

Anaconda Copper Smelter - Current AQB rules require the Anaconda Copper Smelter to control 90 percent of the process input sulfur. A recent reconstruction of the main smelting facility has made it technically possible to achieve that level of control. At present a significant fraction of the gas stream from the main facility is treated in a sulfuric acid plant which extracts the sulfur dioxide from the exhaust gas and converts it to sulfuric acid. This results in about 34 percent overall control. Additional control could be achieved by construction of another acid plant to treat more of the exhaust gas flow.

The Environmental Protection Agency has concluded that control of 86 percent of the process input sulfur is necessary to meet the federal 24-hour primary standard. Because of the meteorology of the Deer Lodge Valley, 86 percent control is expected to

state. In most cases (e.g., Anaconda) the limiting standard is not the annual average, but the one-hour or 24-hour standards. This causes difficulty in estimating costs associated with only the annual standard when the planned control technique is designed for compliance with a relatively more stringent short-term ambient standard or emission standard.

In light of these difficulties, rough estimates of control costs were obtained by consultation with the Montana State Air Quality Bureau (AQB) engineers, representatives of the industrial point sources examined, and EPA analyses. The estimated costs of compliance developed by the subject plant are reported as they were supplied to the AQB. Estimates developed from AQB and other information are reported where available.

It is felt that plant closure or production cutbacks do not warrant consideration as a viable control technique. Although such a control technique obviously would be effective, the probability of closure of any industrial point source examined is virtually zero. Nor are any secondary costs on consumers or workers considered since the costs estimated here will include these costs before they are passed through. Table 15 lists the point sources and their emissions for each of the three analysis areas. A brief analysis of each point source follows.

of 50 ug/m^3 at the ambient monitor. Discrete technology further complicates the estimate. Suppose it is found that a scrubber on an exhaust stack will achieve ambient sulfur dioxide reductions that are twice the amount required by the standard. Then the benefits of a 50 ug/m^3 standard will be compared with the costs of achieving 25 ug/m^3.

The remaining three factors--uniqueness, engineering costs, and incentives--further increase the control cost variability. Most of the industrial point sources examined are unique and, therefore, it is difficult to compare control techniques implemented at other sources and the results of those installations with the sources examined. Each unique industrial point source requires a costly engineering assessment by an air pollution control engineer in order to make an accurate estimate of the control costs.

This leads to the last factor--incentives. Unless the industrial source is forced to comply with a standard, it has no incentive to discover the costs associated with reducing their emissions, i.e., until a standard is enforced upon a point source the burden falls on the receptor rather than the source of pollution.

Arriving at estimates of control costs associated with the alternative annual sulfur dioxide standards is further complicated by the complexity of air pollution laws. There are currently 27 ambient pollutant standards in Montana. These standards apply to 11 different pollutants (six federal and five additional state) for averaging times varying from one hour to one year. Further complicating the situation are emission laws--both federal and

III SULFUR DIOXIDE: CONTROL COSTS

In order to comply with either the NAAQS (80 ug/m^3) or the proposed MAAQS (50 ug/m^3) annual average sulfur dioxide standards, most major point sources of sulfur dioxide will have to reduce their emissions. Theoretically, the identification of a best standard would require control cost functions relating the level of emissions to a cost value.

Unfortunately, control cost functions are applicable only to highly aggregated situations. Development of accurate estimates of control costs has been inhibited by several factors. Among them are (1) lack of accurate dispersion models, (2) discrete technology, (3) the highly individualized circumstance of most point sources (especially the older ones), (4) the expense of engineering assessments, and (5) a lack of incentives.

The implications of these five factors are evident from the following hypothetical example. Suppose a sulfur dioxide point source is forced to comply with the 50 ug/m^3 standard. Suppose further that the current sulfur dioxide emissions from this source are 10,000 tons per year and that an ambient monitor near the point source records an annual sulfur dioxide average of 100 ug/m^3.

The implications of the first limitation, lack of an accurate dispersion model, is that it is not known exactly how much the 10,000 tons per year will have to be reduced to attain a reduction

is due to the urban population and the fertile farming area in the surrounding area.

Table 13

Summary of Annual Benefits Resulting from Alternating Levels of Ambient Sulfur Dioxide Air Pollution in Montana

Category	80 ug/m^3 ($1,000)		50 ug/m^3 ($1,000)	
	High Estimate	Low Estimate	High Estimate	Low Estimate
Health	3,900	800	6,700	1,400
Vegetation	1,000	1,000	1,200	1,200
Materials	100	100	100	100
Visibility	1,200	100	2,000	200
TOTALS	6,200	2,000	10,000	2,900

health remains the largest component of the benefits associated with the 50 ug/m^3 standard. Whereas the health benefits dominate the high estimate, they comprise only 40 percent of the low estimate of benefits associated with complying with an 80 ug/m^3 standard and 48 percent for a 50 ug/m^3 standard.

Table 14

Summary of Area Specific Annual Benefits Resulting from Alternative Ambient Sulfur Dioxide Standards

Area	80 ug/m^3 ($1,000)		50 ug/m^3 ($1,000)	
	High	Low	High	Low
Anaconda	1,100	800	1,500	900
Billings	4,300	800	7,100	1,500
Helena	800	400	1,400	500
TOTALS	6,260	2,000	10,000	2,900

Table 14 provides a summary of the area specific benefits. Evident from the table is the dominance of the Billings area. This

Table 12

Estimated Visibility Benefits Resulting from Alternative Levels of Sulfur Dioxide Air Pollution in Montana

Site	Annual benefits ($1,000)			
	80 ug/m^3		50 ug/m^3	
	High	Low	High	Low
Anaconda	0	0	0	0
Billings	1,200	120	2,000	200
Helena	0	0	0	0
TOTALS	1,200	120	2,000	200

implication of not estimating the amenity/aesthetic effect of sulfur dioxide in its entirety is, of course, that the total aesthetic damage estimates are biased downward. In light of these omissions the damages estimated should be interpreted as a minimum figure.

Summary of Sulfur Dioxide Control Benefits

Table 13 provides a summary of the control benefits estimated in the previous four sections of this chapter. As evident from the table, the variation in the high and low health benefits results in greater than twofold variations in the total benefits of the 80 ug/m^3 and the 50 ug/m^3 standards. Whereas the total high estimates are dominated by the health benefits (63 percent and 67 percent of the total benefits of the 80 ug/m^3 and 50 ug/m^3, respectively), the low estimates are distributed relatively evenly between health and vegetation.

The largest component of the total low estimate of benefits associated with compliance with an 80 ug/m^3 standard is vegetation;

bility conditions. Two large coal-fired power plants recently have been constructed in the area and additional coal development is expected. Thus, asking the respondents what they would be willing to pay to prevent a degradation of their visibility by the power plants or how much they would have to be paid to allow a degradation of visibility (if they had the right of veto) was not an idle exercise. Almost two-thirds of the respondents refused to participate (or insisted on effectively infinite bids) in the "pay to allow" portion of the survey. Even with these respondents excluded, the average bid for this part of the survey is approximately ten times higher than for the pay to prevent question. If expressed as dollars per kilometer change per month, the average willingness-to-pay bid is $0.10 per household. The average compensation bid is $0.94/km/mo.

Table 12 shows the resulting benefit estimate. The 3 km/yr average improvement in visibility at the 80 ug/m^3 standard is estimated to be worth $120,000 per year to the 33,200 households in the Billings area, if they are asked to pay to clean up the pollution. If on the other hand they have an inherent right to good visibility, then the price they are willing to accept to sell that right is ten times greater.

Aside from visibility, other effects of sulfur dioxide on amenities in Montana are difficult to quantify. Damage to ornamental plants was estimated along with that to all other vegetation; it is assumed that damage to works of art is negligible. Possible sulfur dioxide induced damage to animals, the ecosystem as a whole and unaccounted for aesthetics have not been quantified. The

viewed visibility data throughout the West. They found the annual average visibility in Great Falls and Billings to be approximately 100 km. If the loss in visibility calculated above is assumed to approximate the reduction in the annual average visibility from all sources, then the achievement of the 80 ug/m^3 standard would result in an improvement of annual average visibility of 3 km and the achievement of the 50 ug/m^3 standard would bring an improvement of 5 km.

Although there is no market mechanism to express a value of visibility reduction, there are two techniques that can be used to ascertain consumer valuations of atmospheric visibility: (1) the bidding game model, and (2) the household substitution model. The first technique is rather direct. Individuals are asked how much they would pay for an improvement in their situation or require as a bribe to accept a decline in current fortunes. The household substitution approach aims at establishing a link between visibility and already priced market goods that affect leisure decisions. It tries, in other words, to measure the reallocation of time by a consumer in any particular activity when faced with different levels of visibility.

Even though the two techniques are different, they have produced similar prices for visibility in three southwestern studies. Randall et al. (1974), Brookshire et al. (1976) and Blank et al. (1977) have conducted studies of willingness-to-pay to avoid visibility degradation in the Four Corners area of the Southwest. In their bidding game survey Blank et al. (1977) showed respondents a set of photographs of local scenery through three distinct visi-

Idaho. Two major sources upwind of Billings are the Anaconda smelter and the ASARCO smelter, approximately 250 and 175 miles west of Billings, respectively. Several significant sources also are located in the immediate vicinity.

It is possible to make some very rough estimates for Billings to illustrate the magnitude of the effects and to permit some lower bound estimates for visibility degradation due to sulfur dioxide emissions. Latimer et al. (1978) present some generalized relationships between the amount of sulfur dioxide emissions and the reduction in visibility that can be expected at various distances downwind from the source. When used with typical Montana wind speeds, the current emission rates of the sources and the distance between the sources and the viewers, these relations indicate that visibility in Billings would be reduced by eight percent by sulfate from Anaconda and less than one percent by sulfate from ASARCO when Billings lies along the plume trajectory from these sources. The calculation assumes a conversion rate of 0.5 percent per hour and a mixing height above that commonly observed in central Montana. Thus, the model would tend to understate the impact on visibility.

Table 1 indicates that both Anaconda and ASARCO will have to reduce their emissions by about 28 percent to meet the 80 ug/m^3 standard and by about 57 percent to meet the 50 ug/m^3 standard. If the new emission levels are utilized in the Latimer et al. relations the total visibility loss from these sources is estimated to be 5.5 percent at the 80 ug/m^3 standard and 3.5 percent at the 50 ug/m^3 standard.

In a separate phase of their study, Latimer et al (1978) re-

Visibility impairment generally occurs when liquid and solid airborne materials absorb and scatter light. Visibility reduction caused by pollution is related to the size, concentration, and physical characteristics of the particulate pollutants present in the atmosphere. The majority of light-scattering particulates in the area are sulfates.

The amount of sulfate present at any point is primarily a function of the time that has elapsed since the air mass left a source of sulfur dioxide. The sulfur dioxide converts to sulfate at a rate of 0.5 percent (Husar et al. 1978) to 26 percent (Newman et al. 1975) per hour depending on atmospheric conditions and the presence of catalysts and moisture. Since it will require several hours for sufficient conversion to occur to cause significant visibility degradation, the effects will be observed many miles downwind. On the other hand, if there is very little wind, sulfur dioxide emissions may remain close to the source, resulting in high sulfate levels and poor visibility in the immediate vicinity. With detailed knowledge of the meteorological conditions, it is possible to estimate the relationship between sulfur dioxide emissions at one point and visibility degradation at another point. Latimer et al. (1978) developed some meteorological models that present just such an estimate; unfortunately, the necessary meteorological information has not been collected in Montana.

Latimer et al. (1978) report that the days of lower visibility at Great Falls and Billings are primarily associated with winds out of the west. The principal source of sulfur dioxide emissions to the west of Great Falls is the Bunker Hill smelter in K llogg,

however, will pick up other damages, including health and property, to the extent that people are aware of the damage(s) being done to them and their property. Property value studies are exceptionally difficult to use to predict the total economic effect of air pollution because of the many confounding factors.

Waddell's (1974) review and national assessment of air pollution damage estimates a national aesthetic damage of $5.8 billion (in 1970 dollars), of which one-half is attributed to sulfur dioxide. Estimates of effects on animals and the functioning of the ecosystem were not attempted. A principal component of quantified sulfur dioxide induced aesthetic damage is visibility impairment.

Aesthetic loss due to visibility impairment has become a major concern in our society (U.S. House of Representatives, 1977). The National Park Service estimated that the proposed Kaiparowits power plant would have resulted in a loss of $24 million in recreation income and a $78 million loss in use value in Utah over a 35-year period due to the adverse effects on visibility (U.S. Department of Interior , 1976). Similarly, Vars and Sorenson (1972) have estimated an annual loss of at least $30,000 to $45,000 due to smoke and haze in the Salem, Eugene, and Corvallis areas of Oregon. In a Florida study the social aesthetic cost of reduced visibility was estimated at $26.1 million a year. This was greater than the sulfate induced health cost also estimated for Florida (SRI, 1978).

Waggoner and Charlson (1977) present an in-depth review of the relationship between visibility and suspended particulate. An application of their findings to Montana is described below.

are as reported in Tables 1 and 2 (see pages 13 and 15). Relative humidity was obtained from the National Oceanic and Atmospheric Administration (NOAA) Local Climatological Data for 1977. Normals for quarterly averages were used rather than annual averages. This allowed for correlation between high humidity and high ambient concentrations of sulfur dioxide as occurs during certain periods of the year. Since relative humidity data were not available for Anaconda, it was assumed that Anaconda's quarterly relative humidity was five percent less than Helena's, or a maximum of 55 percent. The NOAA national map of relative humidity places Anaconda between the 50 percent to 60 percent isopleths.

As evident in Table 11, the estimated material damage in Montana is largely limited to the Billings area. This is due to the greater population in Billings and the proximity of the sulfur dioxide sources to the population. The sources in Anaconda and Helena are relatively isolated from the population centers. The total benefits of reduced material damage, going from current conditions to an 80 ug/m^3 annual sulfur dioxide standard, are $104,000 annually; to 50 ug/m^3 they are $125,000.

The key variable in the material damage estimate is the relative humidity. It appears that Montana's relatively low humidity results in minimal amounts of damage to metals and paints. However, these estimates are probably substantial understatements of the true material losses attributed to ambient sulfur dioxide.

Aesthetic Benefits

Reductions in property values are often used to determine aesthetic damages induced by air pollution. These estimates

procedure results, however, in an underestimated paint damage since the relationship between ambient sulfur dioxide and paint differs from that represented by the zinc corrosion function. Whereas Haynie and Upham (1970) found relatively high sulfur dioxide and relative humidity thresholds for zinc corrosion,[11] Haynie et al. (1976) found that the relationship between sulfur dioxide and oil base paint erosion was best represented by a zero threshold (for both sulfur dioxide and relative humidity) erosion function. Furthermore, latex paints contain calcium carbonate which is highly reactive with sulfur dioxide (Haynie et al. 1976).

Table 11

Estimated Material Damage Loss and Benefits Resulting from Alternative Levels of Sulfur Dioxide Air Pollution in Montana

Site	Annual loss ($1,000)			Annual Benefit ($1,000)	
	Current	80 ug/m^3	50 ug/m^3	80 ug/m^3	50 ug/m^3
Anaconda	0	0	0	0	0
Billings	123	21	0	102	123
Helena	2	0	0	2	2
TOTALS	125	21	0	104	125

Table 11 shows the results of applying the Gillette zinc economic damage function (Equation (1)) modified to take into account other metals (multiplied by two) and paint damage (multiplied by 1.45). The ambient sulfur dioxide concentration and population data

[11] The zinc corrosion function, evaluated at 60 percent relative humidity, has a 51 ug/m^3 sulfur dioxide threshold. The relative humidity threshold is 49 percent.

attributed to sulfur dioxide and the latter is considered primarily an effect of total suspended particulate pollution.[9] An alternative approach is to follow Salmon (1970) who found that, on a national scale, damage to galvanized metals was about one-half the economic loss attributed to corrosion of all metals.[10] Multiplying the Haynie and Upham zinc corrosion function by a factor of two will take into account the corrosion of all metals. Relative humidity is also accounted for since the zinc function considers it as a variable.

The economic loss ascribed to paint deterioration has been estimated by Salmon (1970) and Spence and Haynie (1972). These estimates are fairly consistent. One possible approach to estimate paint damage in Montana is to use Salmon's estimate of paint damage as a percent of his zinc damage estimate and multiply this factor into the zinc corrosion function developed by Haynie and Upham. Salmon estimated paint damage to be 150 percent of his estimated zinc damage. Yocum and Grappone, however, found that only 30 percent of their paint damage estimate was due to sulfur dioxide; the remainder was due to suspended particulate. This suggests that a factor of .45 could be included in the zinc damage function (Equation (1)) to account for sulfur dioxide induced paint damage.

Because no viable alternative exists, the above-described method for estimating paint damages will be used in this study. This

---

[9] Gillette (1975) specifies that the function estimates "maintenance" costs which usually are composed of both paint damage and soiling.

[10] Salmon (1970) estimated a total metals damage of $1,502 million of which $778 million was attributed to zinc corrosion.

proxy for material exposure to sulfur dioxide.

Table 10

Product Characteristics and Costs of Major Types of Galvanized Products*

Galvanized product	Dollars per capita		UL	TH
	RC replacement values	RC/UL annual replacement costs	ordinary use life, years	thickness of zinc coating um
Building accessories	123.75	2.75	45	26
Wire fencing	20.00	1.00	20	26
Fence posts	27.50	.92	30	54
Wires and gables	30.00	1.50	20	37
Pole line hardware	20.00	.67	30	85

*The dollar estimates are 1972 dollars.

Gillette estimated damage to other metals by utilizing data generated by Battelle Memorial Institute (Fink et al. 1971). By assuming a linear relation between sulfur dioxide levels and damage costs, Gillette proposed a damage function with a threshold of 20 ug/m^3.

$$E = (0.88)\ (SO_2 - 20) \qquad (2)$$

This function proposes a per capita economic loss estimate of 88 cents for each additional ug/m^3 of ambient sulfur dioxide in excess of 20 ug/m^3. The key assumption behind its use is that relative humidity is at the national average. Montana's relative humidity, however, is much less than the national averages; use of this function results in an overestimation of corrosion damage to other metals. It also is not clear whether this function considers only corrosion or whether it also considers soiling. The former is

electrical components. Critical reviews of these studies have been published by Gillette and Upham (1973), Liu and Yu (1976), Waddell (1974), and Yocom and Grappone (1976). Generalized conclusions from the reviews suggest the following:

1. Relative humidity and sulfur dioxide are the key variables.

2. Sulfur dioxide damage occurs primarily to those materials continually exposed to the outdoor environment.

3. Concrete, marble, and limestone are negligibly affected by current levels of sulfur dioxide.

4. Most sulfur dioxide induced economic loss is due to corrosion of ferrous and nonferrous metals and deterioration of paints.

Gillette (1975) developed a model for estimating the economic loss induced by sulfur dioxide on galvanized metals. Gillette converted a zinc (galvanized coating) corrosion function developed by Haynie and Upham (1970) into an economic damage function.

$$E = \frac{(RC)(0.00103)\ (RH - 49)\ SO_2}{TH} - \frac{RC}{UL} \qquad (1)$$

where: E = economic loss per capita
RH = relative humidity
SO_2 = ub/m^3 ambient sulfur dioxide concentration
RC = replacement cost of the metal
TH = thickness of the galvanized coating
UC = useful life of the metal.

If E is a negative value, there is no economic loss due to reduced service life. In this case E is set equal to zero. Values for TH, UL and RC were derived by Gillette for five different categories of metals from industrial indices. They are listed in Table 10. The area's population, assuming that the geographic distribution of materials is similar to that of the population, is used as a

a brief description of the problem.[8] A generation will reap the benefits of a pollution product (e.g. copper) in light of a heavily discounted cost (e.g., devastated alpine environment). A second generation suffers the damage, but argues that the discounted benefits of cleaning up are too small. The result is a third generation stuck with a depleted and poisoned environment.

Conversely this analysis contains a substantial downward bias. With the exception of nonharvestable timber and ornamental plants, the estimation of vegetation benefits fails to account for nonmarket values associated with vegetation such as lichens, mosses, ferns, etc. Williams (1978, p. 9) reports that

> The threat to lower plant species--mosses, ferns, lichens, and liverworts--appears to be particularly severe. Field studies in areas where monitoring for SO_2 has been extensive have defined the ultrasensitivity of this group of organisms. Chronic responses observed in the field suggest that many lower plant species are damaged by SO_2 levels as low as 0.012 ppm (30 ug/m^3). Injury to lower plant floras can result in watershed and aquifer degradation, accelerated soil erosion, reduced soil fertility, reduced water quality, and additional water stress to organisms more tolerant of sulfur pollutants.

Materials Benefits

Sulfur dioxide reacts with various materials in the presence of moisture. This causes damage which results in an economic loss by a reduction in the useful life of the material. Studies have examined sulfur dioxide (most likely after its conversion to sulfuric acid) induced damage to steel, zinc, aluminum, copper, nickel, titanium, cotton, limestone, marble, paint, cellulosic fibers, and

[8] For a more detailed discussion of intergenerational equity see Ferejohn and Page (1978).

define an exposed population is obviously not an accurate portrayal of the exposure area. Sulfur dioxide plumes have been tracked several hundred miles from their source (Wilson et al. 1977). Silver Bow County has been included with Deer Lodge County for this reason.

Also, the broad categorization of the counties into pollution potential classes does not allow for a fully differentiated benefit associated with compliance to a 50 ug/m^3 standard. This results in an underestimation of the incremental benefits in the Anaconda and Helena areas and, possibly, an overestimation in the Billings area.

An additional point that warrants discussion is the potential significance of a vegetation response lag. Because ecosystems require a long time to recover from past pollution damage, it could thus be argued that the benefits from reduced pollution should not be counted until two, ten or even forty years in the future when the full benefits will begin to be received. Under the accepted discounting procedures this could substantially reduce the estimated benefits of reduced timber damage, e.g. a ten year response lag at a six percent discount rate would reduce the estimated timber benefits by half. A forty year response lag would reduce them to one tenth of the estimated amount. With agricultural crops this effect is not as significant because they are harvested annually.

The appropriateness of discounting future benefits concerns intergenerational equity. Although a detailed discussion of this phenomenon is beyond this analysis, the following example provides

however, damage to ornamental plants is assumed to be but one fourth the crop damage. The inclusion of ornamental damage using one-half of the SRI national estimate of average damage to ornamental plants (or one-fourth of crop damage) results in total annual vegetation losses of $1.50 million in Montana under present conditions.

Table 9 lists the counties and corresponding vegetation losses for present conditions and alternatives of the federal annual standard and the state annual standard. The estimated benefits of avoided vegetation losses, going from present conditions to an 80 ug/m^3 annual standard, are $966,000 annually; to a 50 ug/m^3 annual standard the benefits are $1,190,000 annually.

Table 9

Estimated Vegetation Losses and Benefits Resulting from Sulfur Dioxide Air Pollution in Montana*

County	Annual loss ($1,000)			Annual Benefit ($1,000)	
	Current	80 ug/m^3	50 ug/m^3	80 ug/m^3	50 ug/m^3
Deer Lodge) Silver Bow)	830	104	104	726	726
Yellowstone	317	317	93	0	224
Lewis & Clark	357	117	117	240	240
TOTALS	1,504	537	313	966	1,190

*Includes the ornamental damage estimate.

The estimated vegetation damage is a "best" estimate; however, several major shortcomings warrant discussion. The absence of dispersion models for each point source results in crude approximations of exposure to the pollutant. The use of county boundaries to

4 miles south of the ASARCO smelter, 75-80 percent of the pines had nearly totally necrotic needles on the side facing the smelter. Nearly 100 percent of the needles, all ages, were dead for 50-75 percent of their length (Carlson 1978, p. 1).

Scheffer and Hedgcock (1955) summarized a 1911 survey that documented injury to subalpine fir 22 miles from the Anaconda smelter. The survey reported trees with tip necrosis in areas that now are nothing more than bare and badly eroded soil. Sulfur dioxide induced injury to vegetation in the Billings area has been documented by the Environmental Studies Laboratory (EVST) at the University of Montana (EPA 1978a). Monitoring of damage at a site near the Corette power plant in 1977 revealed a high incidence of tip burn and low needle retention in Ponderosa Pine. The EVST also has done extensive monitoring in the Anaconda and Colstrip areas. Sulfur dioxide induced damage to native grasses was found at numerous sites in both areas (EPA 1978a).

Based on these studies it appears safe to conclude that vegetation damage in Montana, due to ambient sulfur dioxide, is not negligible and that the modified SRI model can be used to generate a better estimate of the damage of the alternative concentrations of ambient sulfur dioxide addressed in this analysis.

The SRI study estimated sulfur dioxide induced damage to ornamental plants (private and public such as public gardens and roadside trees) was equal to about one half the crop loss. Their estimation of ornamentals is probably an underestimate; they used replacement costs as an approximation for the value of private ornamental plants and maintenance costs for the value of public ornamental plants. Considering the generally rural status of Montana,

their analysis, is a subject of much debate in the literature.[6] Whether these limitations are substantial enough to account for a difference of at least tenfold in estimates is not known. Regardless, the presence of a potentially wide error margin is evident.

In 1974 the Forest Service conducted a field survey near the Hoerner-Waldorf pulp and paper mill in Missoula. The report (Carlson et al. 1974) concludes that the potential exists for a decrease in timber yield of 2.5 MMBF of Douglas Fir if sulfur dioxide fumigation persists. Assuming this loss occurs over a five to ten year period,[7] it could result in an annual loss of between $16,000 and $32,000 from this one source. Application of the modified SRI model to Missoula County (a pollution potential of Class 1) yields an estimated sulfur dioxide timber damage of $28,000 per year. This is reasonable because the Hoerner-Waldorf mill accounts for only 75 percent of the sulfur dioxide point sources in the county (Gelhaus et al. 1978).

The Forest Service also has monitored sulfur dioxide damage to forests in Deer Lodge County (Scheffer and Hedgcock, 1955) and Lewis and Clark County (Carlson, 1978a). Although estimates of yield losses were not made, Carlson's investigation in March 1978 revealed that

---

[6] Asmus and Stroup (1972) use a leaf damage elasticity of .302 for alfalfa and an average elasticity for barley of .168. For alfalfa this implies that a 30 percent leaf injury would result in a nine percent yield loss.

[7] A personal interview with Clint Carlson, Forest Insect and Disease Management, U.S. Forest Service, Missoula, Montana, April, 1979, revealed that 10 years is a conservative assumption; the yield loss may have occurred within a four to five year period.

Table 8

Previous Statewide Field Surveys

Author	Year of Survey	State	Economic loss (millions 1978$)
Weidensaul and Lacasse (1970)	1969	Pennsylvania	6.4
Lacasse (1971)	1970-1971	Pennsylvania	.3
Millecan (1971)	1970	California	44.8
Feliciano (1972)	1971	New Jersey	1.9
Pell (1973)	1972	New Jersey	.2
Naegle et al. (1972)	1971-1972	New England	1.6
Millecan (1976)	1974	California	72.2

in alfalfa and barley. Whereas the modified SRI methodology yields values of $41,745 and $4,081 for alfalfa and barley, Asmus and Stroup estimated $3,927 and $1,191 (converted to 1978 dollars) or about 10 percent and 30 percent of the SRI estimates. The Asmus and Stroup analysis was also conducted prior to an installation of an acid plant which reduced the smelter's sulfur dioxide emissions from an estimated 80,000 tons per year to its current rate of 14,000 tons per year.

Asmus and Stroup however mentioned several factors which "almost certainly bias downwards" (1972, p. 26) their estimates. One such is the inability of their long-term dispersion model to pick up short-term variations in sulfur dioxide concentration. Another was their inability to account for certain climatic conditions such as presence of inversions. They also limited exposure time to daylight hours and the leaf damage/yield loss function, a key component in

Table 7

Estimated Annual Value of Timber per Analyzed County

County	Timbered lands (1,000 acres)			Value per year ($1,000)
	Private*	National forest**	Total	
Deer Lodge) Silver Bow)	51	298	349	4,445
Yellowstone	24	0	24	305
Lewis & Clark	129	999***	1,127	14,344

*Acres of private timber per county were obtained from the Property Assessment Division of the Montana Department of Revenue (V. Bickford, personal communication, 1978).

**The National Forest Acreage per county was obtained from the Forest Service Northern Region (J. Baker, personal communication, 1978).

***Includes three acres of state-owned forest.

duced agricultural damage of $1.20 million per year under present conditions. This estimate may be compared to other state specific and national estimates. Table 8 lists some statewide field surveys. As the table illustrates, estimates for the same state may vary widely, particularly in the East where climate is more variable The key variables are air pollution, crop value, and environmental conditions; the latter are uncontrolled and could cause substantial variation. Most of the loss reported in Table 8 is attributed to oxidants.

Several studies have dealt with sulfur dioxide induced vegetation damage in Montana. Asmus and Stroup (1972) looked at the effects of sulfur dioxide from ASARCO's lead smelter in Lewis and Clark County. They combined a dispersion model with a leaf damage function to obtain estimates of economic loss from yield reductions

acre. These figures suggest that the current productivity of Montana's forest resources is approximately 63 cubic feet per acre.

Green and Setzer (1974) use a cubic foot (CF) to board foot (BF) conversion factor of 3.7 BF to 1 CF. Current research within the School of Forestry, University of Montana, indicates a Montana specific conversion factor of 3.12 BF to 1 CF.[4] The conversion factor yields an estimated net annual growth of Montana's forest resources of 196.6 BF per acre. Weighting current stumpage values[5] by species according to percent occurrence as reported in Green and Setzer, yields a stumpage of $64.7 per thousand board feet (MBF). Coupled with the growth rate, the resulting value per acre of Montana's forests is $12.72 per acre per year. This value, multiplied by the number of acres per county, yields estimates of the annual value of the forest resources in each area.

Table 7 lists the counties, acres of private and national forest timber, and the estimated value in terms of net annual growth. This method of estimating the annual value of Montana's forest resources in each county rests on a commerical harvest valuation of noncommercial timber. It assumes that the annual growth value is a minimum value for the nonharvest uses of forest land such as wilderness recreation.

As shown in Table 6, application of the modified SRI model to Montana yields a statewide annual estimate of sulfur dioxide in-

---

[4]Alan McQuillan, University of Montana, personal communication, July, 1978.

[5]Because of the variation in this value, the previous four quarters of the Northern Region High Bid were averaged.

Table 6

Estimated Crop Valuation and Economic Damage
Resulting from Alternative Levels of
Sulfur Dioxide Air Pollution
in Montana

County Crop	Value ($1,000)	Loss ($1,000) Present	80 ug/m^3	50 ug/m^3
Deer Lodge)				
Silver Bow)		664	83	83
Alfalfa	786	94	12	12
Barley	116	7	1	1
Hay	749	19	2	2
Oats	42	1	0	0
Timber	4,445	533	67	67
Wheat	74	9	0	1
Yellowstone		253	253	74
Alfalfa	2,164	32	32	11
Barley	2,252	16	16	5
Beans	280	2	2	1
Hay	424	1	1	0
Oats	280	2	2	1
Sugar beets	8,684	26	26	0
Timber	305	5	5	2
Wheat	11,296	169	169	56
Lewis & Clark		286	93	93
Alfalfa	2,783	42	14	14
Barley	583	4	1	1
Hay	1,497	4	0	0
Oats	687	5	1	1
Timber	14,334	215	72	72
Wheat	1,026	15	5	5
TOTALS		1,203	430	251

although some land is highly productive, most is in the middle or lower end of the range of growth potential. In productivity, Montana's forested land compares favorably with the Rocky Mountain region and the United States as a whole.

They estimate a current gross annual growth rate of 75 cubic feet per acre. Green and Setzer (1974) estimate an annual mortality rate for the northern Rocky Mountain states of 11 cubic feet per

Table 5

Crop Damage Multipliers for Exposed Crops

Crop	Damage class	Pollution potential class 1	2	3	4	5
Alfalfa	A	.002	.055	.015	.040	.120
Barley	B	.000	.002	.007	.022	.064
Beans	B	.000	.002	.007	.022	.064
Hay	C	.000	.000	.003	.008	.025
Oats	B	.000	.002	.007	.022	.064
Sugar beets	C	.000	.000	.003	.008	.025
Timber	A	.002	.005	.015	.040	.120
Wheat	A	.002	.005	.015	.040	.120

Appendix B provides a summary of these reports and the rationale for revising several of the damage classes. The multipliers represent the proportion of the county crop value lost annually due to sulfur dioxide air pollution. For example, the damage multiplier for alfalfa in a pollution potential Class 3 county is .015. This implies that the alfalfa in the county will suffer an average of 1.5 percent yield reduction, i.e., while some areas near the point source may suffer high yield losses, the majority of the county will not be affected.

Table 6 summarizes the application of the modified SRI model to Montana. The crop values listed are Montana Department of Agriculture (1976) estimates for 1974 and 1975 which have been averaged. The value of timber in each county is in terms of net annual growth, i.e., gross growth less mortality. Schweitzer et al. (1975, p. 12) have characterized Montana's forests as follows:

Table 4

Pollution Potential Class for Each County

County	Present sulfur dioxide tons/year*	Class		
		Present	80 ug/m^3	50 ug/m^3
Anaconda Deer Lodge) Silver Bow)	281,750	5	3	3
Billings Yellowstone	34,850	3	3	2
Helena Lewis & Clark**	14,000	3	2	2

*Gelhaus et al. (1978)

**SRI criteria would include Lewis and Clark County as Class 5 but, considering existing pollution controls, it was given an initial Class 3 standing.

the different standards vary dramatically from source to source. Furthermore, even compliance with the standard does not reflect the magnitude of the effect of a source. Large, high-level sources may affect vegetation over a much larger area even though they comply with the standard at the present monitors. Smaller, low level sources can violate the standards, but they do not affect a very large area. In the final analysis the class assignment is subjective.

Table 5 lists the exposed Montana crops and their corresponding damage functions in terms of a multiplier for each pollution potential class. Although the SRI multipliers remain unchanged, several crop damage classes were modified to reflect more recent information as reported by Guderian (1977), Materna (1973), and EPA (1973).

On the positive side, a comparison of the original SRI results with published field surveys indicates general consistency. Waddell (1974, p. 99) concludes his review of comprehensive vegetation damage techniques by saying

> the loss estimate . . .generated in the SRI study for 1964 is the most defensible of those reviewed. Also, the SRI estimates are consistent with the individual estimates for California, Pennsylvania and elsewhere.

Leung et al. (1977, p. 96) conclude their review of damage estimation techniques: "It may be necessary or desirable to continue using less objective models for assessments and analyses until more objective methods are available." For purposes of this analysis the SRI model, modified where possible according to the availability of knowledge and data, is used to generate a "best" vegetation damage estimate.

Table 4 lists the pollution potential class of the Montana counties within the analysis area. The original SRI approach assigned counties to classes based on the number or type of sulfur dioxide sources in a county. While this may have been reasonable during an era of relatively uncontrolled emissions, it is clear that it ignores the effect of existing pollution control equipment on pollution potential. The pollution potential classes therefore have have been reassigned under the alternative standards to reflect the lower level of sulfur dioxide emissions.

One of the primary difficulties with this approach is evident in the table. Because the five classes are necessarily broad, the changes in pollutant emissions necessary to achieve compliance with different standards cannot be fully differentiated. As explained in Chapter 3 the changes in emissions necessary to meet

(Benedict et al. 1973) grouped SMSA counties into pollution potential classes on a scale of 0 to 5 according to the presence of sulfur dioxide emitting industries. The scientific literature was reviewed to determine damage indices for each agricultural crop. The damage indices considered the resistance of the crop and the susceptibility of the economic portion of the plant. The damage index and the pollution potential yielded a countywide total crop damage estimate.

Although it is a landmark study, the SRI methodology has some serious limitations. The following discussion summarizes the criticisms raised by others. Waddell (1974, p. 99) argues that the SRI's damage index factors are "best guesses" and "reflect a lower bound of the true plant-associated losses due to air pollution." Jansson (1975) observed that some plumes exceed county boundaries while other point sources affect only a small portion of a large county. Hershaft et al!s(1976) review points out such shortcomings as the failure to incorporate other uncontrolled factors (climatic conditions) and the failure to account for the indirect loss occurring because of the substitution of more resistant but less productive crops. Heck (1976) pointed out that a major shortcoming of such vegetation studies is the low estimation of yield loss when the absence of visible damage is taken to mean the absence of physical damage.

Leung et al. (1977, p. 88) report, in regard to the SRI study, that a

> number of approximations and subjective judgments were used in this method of loss estimation . . .(and) there is no way presently to test the accuracy of the SRI loss estimates. With so many unverified assumptions in the method the values obtained may not be presumed to have great accuracy.

the modeling, by a qualified meteorologist, of at least seven point sources and an inventory of exposed vegetation in each area modeled. Furthermore, ambient sulfur dioxide damage functions for the eight vegetation types examined are virtually non-existent. The currently available information concerning the relationship between plant yield and ambient sulfur dioxide is based primarily on studies of short-term exposure to relatively high concentrations as opposed to the chronic effects associated with annual average concentrations.

Accepting the impossibility of applying the most theoretically appealing methodology, one must fall back to a less appealing one. The most widely used method of assessing air pollution induced vegetation damage on a statewide basis is a field survey. Field surveys have been used to estimate vegetation damage since 1949. The first survey performed for a whole state was conducted in 1969 by Weidensaul and Lacasse (1970). Their survey of air pollution induced vegetation damage in Pennsylvania was followed by numerous others--primarily in the industrialized northeastern United States and California. The accuracy of a field survey critically depends on the quality of agricultural technicians trained to objectively estimate leaf injury and the associated yield losses on a field by field basis. The cost of conducting a field survey was substantially beyond the funds available for this study.

Two alternatives remain. One is to assume that sulfur dioxide induced vegetation damage is negligible. The other, that adopted in this analysis, is to pursue a "best guess" based on a methodology developed by the Stanford Research Institute (SRI). The SRI analysis

both the linear coefficient and the value attached to a premature death. For example, the $381,000 benefits derived for Anaconda are reduced 36 percent (to $243,000) by using the adjusted coefficient and mortality. It is reduced 68 percent (to $123,000) by using the foregone earnings approach to valuing human life. Use of both factors (the low estimate) reduces the annual health benefits in Anaconda by 79 percent (to $79,000).

Table 3

Estimated Annual Health Benefits Resulting from Alternative Levels of Sulfur Dioxide Air Pollution In Montana

Site	80 ug/m^3 ($1,000)		50 ug/m^3 ($1,000)	
	High	Low	High	Low
Anaconda	381	79	780	154
Billings	2,977	611	4,756	998
Helena	520	111	1,163	239
TOTALS*	3,878	801	6,699	1,391

*Some columns may not add due to independent rounding.

Vegetation Benefits

Previous assessments of air pollution induced vegetation damage have been based on any of three methodologies. The most theoretically appealing of these combines dispersion models or ambient monitoring with plant damage functions that relate the ambient sulfur dioxide concentrations directly to yield losses, or to leaf injury which, in turn, must be transformed into yield losses. Very few complete analyses of this type have been conducted due to the substantial information requirements. Application of a dispersion model/damage function type of methodology to this analysis requires

theoretically valid than foregone earnings, but it is still probably a low estimate due to the lower than average risk aversion of the occupational sample.

Lave and Seskin's average foregone earnings value per death, corrected to 1978 dollars, is $51,790. The wage differential approach (Thaler and Rosen 1976) places a value of around $400,000 per death (in 1978 dollars). The Lave and Seskin estimate of indirect mortality costs is $104.6 billion (1978 dollars). An alternative estimate, based on a wage differential approach, is $806.3 billion. The latter value is used in this analysis to derive the high estimate; the former, the low estimate.

Lave and Seskin's estimate of direct expenditures and indirect morbidity costs used with the Thaler-Rosen mortality estimate results in a total health cost of $1,037.0 billion. In per capita terms this is $4,823 per death. Based on the monitoring averages in the urban areas of Helena, Billings and Anaconda, it is assumed that the national average may be reasonably applied.

The 0.83 percent reduction in morbidity and mortality costs in Anaconda associated with an 80 ug/m^3 standard is therefore predicted to result in a $40.03 reduction in health costs (0.83 percent of $4,823) per capita. For a population of 9,509 this is an annual health benefit in Anaconda of $381,000 associated with achieving an 80 ug/m^3 annual standard as reported in Table 3. Other entries in Table 3 are similarly derived. Benefits are reported for reduction to the federal primary standard (80 ug/m^3) and reduction to the state 50 ug/m^3 standard.

Evident from the table is the sensitivity of the estimates to

Table 2

Estimated Reduction in Mortality Associated With Reduced Sulfur Dioxide Pollution

Site	Population* and percent	Percent reduction in mortality			
		80 ug/m^3		50 ug/m^3	
		High	Low	High	Low
Anaconda					
Post Office	9,224 = 97%	0.76	0.49	1.56	1.01
Hwy. Junction	285 = 3%	2.99	1.93	6.12	3.94
(Population Weighted Av.)		0.83	0.53	1.70	1.04
Billings					
N. 27th	60,226 = 80%	0.0	0.0	0.0	0.0
Lockwood	7,528 = 10%	1.07	0.69	2.84	1.83
CENEX Farm	7,528 = 10%	7.17	4.55	10.30	6.63
(Population Weighted Av.)		0.82	0.52	1.31	0.85
Helena					
Cogswell	25,820 = 91%	0.32	0.21	0.71	0.46
East Stack	1,986 = 7%	0.86	0.55	1.86	1.20
Microwave	284 = 1%	0.71	0.46	1.53	0.99
Saddle Mtn.	142 = .5%	0.78	0.50	1.69	1.09
Broudy Farm	142 = .5%	2.67	1.73	5.82	3.75
(Population Weighted Av.)		0.38	0.25	0.83	0.54

*The population data used is a 1978 projection by the Department of Community Affairs (1977). The total area population has been apportioned to the monitoring sites in the area.

The alternative is an implicit value approach based on wage differentials as a function of voluntary occupational risks. This approach is an empirical measure of how much people have to be paid in order to face a higher probability of death in their work. The situation is closely analogous to that in which pollution increases the probability of disease or death; the intent is to estimate the value to people of reducing this risk a certain amount. It is more

mortality in Anaconda associated with an 80 ug/m^3 sulfur dioxide standard is 0.83 percent. The low estimate is calculated in the same manner. Similar calculations can be repeated for Billings and Helena for both 80 ug/m^3 and 50 ug/m^3 standards. The results are shown in Table 2. These percentages (following Lave and Seskin) are assumed to apply to both mortality and morbidity.

The fourth and last analysis step is to assign values to the reduced health effects. Lave and Seskin use Cooper and Rice (1976) estimates of national health costs of $75.2 billion (1972 dollars) for direct expenditures (both mortality and morbidity) and $99.7 billion for indirect expenditures (both mortality and morbidity). The direct expenditures are such things as medical and funeral costs. The indirect expenditures are strictly foregone earnings. Of the $99.7 billion indirect expenditures, $42 billion were related to morbidity. The remainder ($57.7 billion) were estimates of foregone earnings from premature death. Lave and Seskin merely adjusted the values to account for inflation and real price increases (price increases in excess of the general rate of inflation) to arrive at their estimates of $154.4 billion (1978 dollars) direct expenditures and $180.0 billion indirect expenditures. Of the $180.0 billion indirect expenditures, $76.3 billion are foregone earnings due to morbidity. The remainder, $103.7 billion, is attributed to foregone earnings due to premature death. This approach to valuing human life is that taken in court cases involving compensation. It essentially views a person's value as a piece of capital equipment. The problem is that this approach does not reveal how the person valued his life, only what his earnings would have been. There is no necessary connection.

Table 1

Reduction in Sulfur Dioxide Ambient Pollution Levels Resulting from an 80 ug/m^3 or 50 ug/m^3 Standard

Site	Mean Ambient SO_2	Resulting mean SO_2 change 80 ug/m^3	Resulting mean SO_2 change 50 ug/m^3
Anaconda			
Post Office	31.5 ug/m^3	7.3 ug/m^3	15.0 ug/m^3
Highway Junction	108.7	28.7	58.7
Billings			
N. 27th	5.7	.0	.0
Lockwood	77.2	10.3	27.2
CENEX Farm	148.7	68.7	98.7
Helena			
Cogswell	17.2	3.1	6.8
East Stack	37.2	8.2	17.8
Microwave	31.5	6.8	14.7
Saddle Mountain	34.3	7.5	16.2
Broudy Farm	105.8	25.8	55.8

*The ambient sulfur dioxide data are the official Montana State Air Quality Bureau readings for 1977 as reported in Gelhaus et al. (1978).

The third step in the analysis is to calculate the percentage reduction in Montana mortality resulting from compliance with the alternative standards. In Anaconda, for example, compliance with the 80 ug/m^3 standard results in a decrease of 7.3 ug/m^3 at the Post Office site (see Table 1). For the high estimate this results in 7.3 fewer deaths per 100,000 population (7.3 x 1.01), a 0.76 percent reduction in the unadjusted Montana mortality rate (7.37/968.10 x 100). A similar calculation at the other Anaconda monitoring site (Highway Junction) results in a 2.99 percent reduction. Based on these two sites, the population-weighted mean reduction in total

Appendix A provides the Lave and Seskin equations, the derivation of the two linear coefficients, and the calculated unadjusted and adjusted Montana mortality rates. When converted to a linear coefficient, the average of the unadjusted elasticities correspond to a linear relationship such that a one ug/m^3 decrease in ambient sulfur dioxide results in a 1.01 unit change in the total mortality rate (deaths per 100,000 population). The average adjusted elasticity results in a .65 linear coefficient. Montana's unadjusted and adjusted mortality rates were 968.16 and 981.34 deaths per 100,000 population, respectively.

The second part of the analysis is the identification of the reduction in ambient pollution that results from compliance with a given pollution standard. To achieve the standards, the major point sources in Anaconda, Billings, and Helena will be required to modify or reduce their emissions significantly. Table 1 lists the current stations and most recent published mean ambient sulfur dioxide readings.

In absence of accurate dispersion modeling in the areas examined, a uniform emission rollback technique was applied to each area to estimate the ambient conditions resulting from compliance to the alternative standards. The uniform emission rollback technique assumes a linear relationship between emissions and ambient concentrations; it takes into account background concentrations of ambient pollutants. This approach is a common one in the literature--even most diffusion models are linear in emissions. The estimated reductions in ambient sulfur dioxide resulting from compliance to alternative ambient standards of 80 ug/m^3 and 50 ug/m^3 are listed in Table 1.

measured by the minimum, mean and maximum of biweekly readings) resulted in a .0216 percent to .0548 percent reduction in total mortality rates depending on the inclusion of other pollution variables. When the mortality rates were adjusted to account for different age-race-sex proportions,[1] the resulting elasticities were .0099 percent to .0395 percent. Sulfur dioxide concentrations experienced in Montana cities are similar to the average of the cities studied by Lave and Seskin.[2]

In this analysis an average of the unadjusted elasticities and Montana's crude mortality rate is used to derive a high estimate of health benefits. An average of the adjusted elasticities and an age-race adjusted Montana mortality rate is used to generate the low estimates.

These elasticities correspond to linear coefficients that measure the response of mortality rates to a one ug/m^3 decrease in ambient sulfur dioxide. This linear relationship is used in this analysis because the actual statistical estimate is linear and because the alternative of assuming constant elasticity results in an overestimate for values below the mean and an underestimate for values above the sample mean.[3]

---

[1]The adjustment procedure allows for correction of variation in mortality rates caused by differing age-race-sex proportions in the population, e.g., the mortality rate of Miami would be adjusted to take into account a high population of elderly people.

[2]The population weighted mean current SO_2 concentration for Montana is 25.6 ug/m^3 (see Table 1, p. 13); the national sample mean is 33.0 ug/m^3 (see Appendix A, Table A.3).

[3]It was found, for example, that the benefits of pollution reduction in Billings to a 50 ug/m^3 level are generally overestimated by about 30 percent if the Lave and Seskin assumption of constant elasticity (rather than linearity) is followed.

variables (e.g., region, population, change, occupation, climate, home heating characteristics) are added; interactions among the air pollution variables and between them and the socioeconomic variables are examined; more refined mortality rates (infant, age-sex-race adjusted, age-sex-race specific, and disease specific rates) are substituted for the total mortality rate; a test of the contribution of omitted variables (by substituting suicide, crime, and venereal disease rates for mortality rates to determine if the air pollution variables are serving as surrogates for omitted variables in explaining these clearly non-pollution-related social ills) is made; the residuals are analyzed; a cross-legged, cross-sectional test for uncontrolled variables is performed; and additional air pollution variables are added and the interaction examined.

This analysis applies the methodology and results of the Lave and Seskin (1977) study to Montana.

The Lave and Seskin methodology requires four basic steps: (1) establish the relationship between the air pollution-related mortality and a given level of pollution, (2) calculate the actual percentage reduction in air pollution required to realize the standards, (3) calculate the decrease in mortality from (1) and (2) and assume that this decrease in mortality will be accompanied by an equal percentage decrease in morbidity, and (4) compute a benefit value equal to the same percentage reduction in per capita health costs using the predicted percentage reduction in mortality and morbidity.

A similar four-step methodology was followed in order to apply this model to Montana. It was found that the resulting health benefits were highly sensitive to steps (1) and (4)--the actual dose-response function and the value of the decreased health effects. Variations in those steps were used to generate high and low estimates of health benefits.

Lave and Seskin found that, based on a 1969 sample of 69 cities, a one percent reduction in ambient sulfur dioxide air pollution (as

II SULFUR DIOXIDE: CONTROL BENEFITS

The economic effects of sulfur dioxide air pollution can be grouped into four categories: (1) health, (2) vegetation, (3) materials, and (4) amenities.

Health Benefits

Numerous studies have investigated the correlation between ambient sulfur dioxide and mortality (death) and morbidity (illness). Among the most notable are those by Schwing and McDonald (1976), Liu and Yu (1976), Lave and Seskin (1977), and Mendolsohn and Orcutt (1978). Each of these studies has produced results that are within the same order of magnitude.

The most useful for our purposes here is the study by Lave and Seskin (1977). This recent publication summarizes 10 years of work during which time the authors explored the statistical relationship of ambient pollution levels and total mortality. The basic method was a linear regression analysis applied to epidemiological, demographic, and socioeconomic data for a large number of cities in the United States for the years 1960, 1961 and 1969.

Robert Haveman's (1979, p. 141) review of the Lave and Seskin analysis emphasizes how extensive their efforts were.

> The catalogue of variations is impressive: a principal components analysis is used to select air pollution variables for inclusion in the regression; a jackknife analysis is employed to test the sensitivity of the results to extreme observations; the analyses are replicated on 1961 and 1969 data; specifications involving quadratic terms, a linear spline, and a split sample are attempted; additional

Figure 1 demonstrates the rationale. Associated with increasing levels of clean air (air pollution control) are increasing total benefits and increasing total costs. The optimal level of clean air results in a maximum level of net benefits to society.

Although the methodology suggested in Figure 1 is theoretically ideal for purposes of this analysis, practically it is not possible to derive the continuous functions f and g. Due to the unavailability of the required information, this analysis considers the benefits and costs associated with only two alternative standards for sulfur dioxide (in three Montana areas where sufficient ambient monitoring has been performed) and one standard for fluoride (in the vicinity of the two major sources).

The alternative sulfur dioxide standards addressed are the National Ambient Air Quality Standard (NAAQS) of 80 ug/m^3 arithmetic annual average and the present Montana Ambient Air Quality Standard (MAAQS) of 50 ug/m^3 arithmetic annual average. The three areas examined are Anaconda, Billings, and Helena. These account for 96 percent of the point source sulfur dioxide emissions in Montana (Gelhaus et al. 1978). All three currently have ambient sulfur dioxide concentrations in excess of the MAAQS standard (50 ug/m^3).

animal, plant, or material--the so-called dose-response function, and (3) the control technology (or other pollution reducing approaches such as different inputs or reduced production) that will achieve a given level of emission reduction. Given physical relationships, values must be placed on the extent of the damage and the resources used for control.

Given the availability of this information, an optimal level of control can be identified by examining the costs and benefits of air pollution control. The methodology, in functional notation, follows.

1. Ambient sulfur dioxide = f_1 (point source emissions).
2. Physical damage = f_2 (ambient sulfur dioxide).
3. Control benefit = f_3 (physical damage).
4. Emission reduction = g_1 (control technology).
5. Control cost = g_2 (emission reduction).
6. Net social benefit = control benefit - control cost.

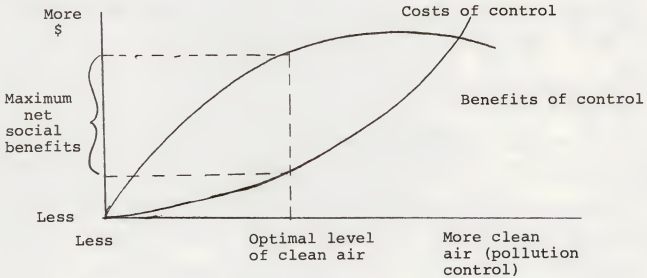

Figure 1

The Theoretical Basis for Selection of an Optimal Level of Clean Air.

As discussed previously, our results do not lend support to the threshold concept. When we examined alternative specifications, we found that generally a simple linear specification "fit" the data as well as other functional forms. We found (for the air pollutants under consideration) little indication that specific levels could be considered "safe" levels, below which no health effects could be detected. Given our findings, we feel that the notion of an air pollution standard (or threshold) for a pollutant that will "protect the public health or welfare" is not meaningful. It translates into setting standards on the basis of damages (or benefits) alone. Instead, we would argue that standards should be based on benefit-cost trade-offs. That is, we believe that society must weigh the costs and benefits of achieving various levels of air quality, and once a desired level is selected, the standards corresponding to it should be determined.

Even if no health effects exist at low levels of pollution, a definite value in clean air remains that is associated with the risk aversion attitudes of the public. That is, there is a value associated with reducing the potential for adverse health effects. Even with a threshold of effects, some members of the public would be willing to pay to reduce their perceived risk by further decreasing the ambient pollution below the threshold. For both of the above reasons, this study abandons the distinction in the Montana Clean Air Act between human health effects and other effects and treats all effects symmetrically.

Methodology

In order to identify the best air quality standard based on efficiency criteria, two general types of information are needed: physical relationships and values. The key physical relationship include three items: (1) the relationship between actual emissions and the ambient air quality which can be determined by sufficient monitoring sites or through dispersion models, (2) the effect of a given level of pollution (ambient level) on receptors--human,

of a gain to one individual compared to a loss to another must be based on political decisions. Ethical concerns are likewise ultimately a political consideration.

This paper provides an analysis of alternative ambient air quality standards based on the efficiency criterion. The selection of efficiency as a criterion to allocate Montana's clean air is generally in compliance with the legal mandate set forth by the Clean Air Act of Montana. However, an apparent contradiction does exist with respect to human health, where essentially ethical considerations are overriding. Section 69-3905 of the Clean Air Act of Montana, R.C.M. 1947, requires the Board of Health and Environmental Sciences to establish ambient air standards that

> achieve and maintain such levels of air quality as will protect human health and safety, and to the greatest degree practicable, prevent injury to plant and animal life and property, foster the comfort and convenience of the people, promote the economic and social development of this state, and facilitate the enjoyment of the natural attractions of this state.

Under this legal mandate ambient air standards must be based on a combination of ethical and efficiency criteria--ethical to the extent that standards must be set at a level that will at least protect public health with the efficiency criterion used only when going beyond the health threshold to protect vegetation, materials, aesthetics, or other welfare values. With respect to sulfur dioxide, evidence suggests that a threshold level of ambient sulfur dioxide below which no health effect occurs may be either nonexistent or at a very low level. For example, Lave and Seskin (1977, p. 316) argue:

I - INTRODUCTION AND METHODOLOGY

Introduction

Increasing public awareness has resulted in a greater demand for clean air in Montana. However, because of its public good characteristics, clean air is not allocated by market mechanisms; thus a collective decision-making procedure is required to allocate it among competing, mutually exclusive uses. The basic trade-off is between using clean air to dispose and disperse wastes and the benefits associated with an unpolluted atmosphere (i.e., health, vegetation, aesthetics, etc.).

Several basic criteria exist to allocate clean air among users. The efficiency criterion pursues an allocation based on maximizing the net social benefits associated with alternative levels of clean air. The distributional criterion examines how these net social benefits are shared or distributed among different groups in society: workers, consumers, property owners, stockholders, proprietors, and the general public. The ethical criterion considers, of course, issues of right and wrong, e.g., the ethical sanction against destruction of a species of plant or animal. The economist can recommend a best allocation (assuming data availability) on efficiency grounds. Distributional implications (who will benefit, who will lose from a given allocation) can be described by economists, but the relative worth

million that may permit the plant to meet both standards. The ASARCO lead smelter in Helena recently installed control equipment that may enable it to meet both standards. Approximately $40 million was spent on the control program.

When control costs are compared to the estimated benefits of control, it is found that for both the high and low estimates, the additional costs of moving from the federal to the more stringent state standard is roughly equal to the additional benefits. This is the best measure of economic efficiency and it suggests that the economically optimal standard in Montana is in the vicinity of the existing state standard.

The two major sources of fluoride air pollution in Montana, the Anaconda Aluminum plant and the Stauffer Chemical phosphorous plant, have recently begun installation of new control equipment that is expected to result in both plants meeting the existing state fluoride air quality standards (for a 24-hour average). Estimates are reported for damages from fluorides in the Columbia Falls and Ramsay areas. In each instance, the analysis indicates that the present control programs are economically justified, but further indicate that new control programs would not be economically justified if the estimated costs and benefits are approximately correct.

included alfalfa, wheat, and timber. The estimated economic benefits were approximately $800 thousand per year for meeting the federal standard and approximately $1 million per year if the state standard were met. Damage to materials, primarily galvanized zinc surfaces and paints, was estimated to be approximately $100 thousand per year in both cases. Finally, estimates were made for the loss of visibility in the Billings area. Depending on the choice of assumptions regarding who "owns" clean air, the annual value of improved visibility is calculated to be between $100 thousand and $1 million for achieving the federal standard and $200 thousand to $2 million for achieving the state standard.

The costs of reducing emissions to meet the federal and state standards were estimated for the seven largest sources of sulfur dioxide in Montana. At Anaconda Copper a $21 million acid plant is expected to reduce emissions sufficiently to achieve both the federal and state standards. The CENEX petroleum refinery in Billings already is planning to spend about $5 million to meet the federal standards. An additional $1 million may have to be spent to meet the state standard. The controls needed by Montana Power's Corette plant to meet the state standard could cost between $7 million and $11 million, depending on the engineering difficulty. The Exxon refinery might have to spend about $9 million on controls to meet the state standard. No additional control would be required at either the Corette power plant or the Exxon refinery to meet the federal standards. The Conoco refinery does not appear to require any additional controls to meet either standard. Montana Sulfur already has agreed to install a new stack for less than $1

SUMMARY

A benefit-cost analysis of air pollution control programs requires a wide range of information, which can be very time consuming to collect in detail. The current levels of air pollution must be known, as must the levels that could be obtained with control of the sources. Then, estimates must be calculated of the effects expected at each level of pollution, the value to society of avoiding each effect, and the costs of accomplishing the proposed control. The relationships between pollution levels and effects are only poorly understood and exact estimates of control costs would require detailed engineering investigations. As a result, it is possible to produce unambiguous results only when either the benefits or costs are overwhelming in comparison to the other.

This report estimates the change in mortality rates that could be anticipated in Helena, Anaconda, and Billings if sulfur dioxide emissions were reduced to meet the existing federal and state ambient air quality standards. Using two procedures for calculating the health effects and two values for the reduction in risk to life and health, estimates of social economic benefit were obtained for achieving the federal standard ($1 million to $4 million per year) and the state standard ($1 million to $7 million per year). Estimates for the loss of agricultural crops and ornamental plants in four Montana counties were calculated. The crops

TABLE OF CONTENTS

Chapter		Page
SUMMARY		1
I	INTRODUCTION AND METHODOLOGY	4
II	SULFUR DIOXIDE: CONTROL BENEFITS	9
	Health Benefits	9
	Vegetation Benefits	17
	Materials Benefits	31
	Aesthetic Benefits	36
	Summary	42
III	SULFUR DIOXIDE: CONTROL BENEFITS.	45
	Analysis of Point Sources.	48
	Summary	55
IV	SULFUR DIOXIDE: ANALYSIS AND DISCUSSION	59
	Analysis of Alternative Standards.	59
	Conclusion and Policy Implications	67
V	FLUORIDES	70
	Anaconda Aluminum Plant	71
	Stauffer Chemical Company	74
	Analysis and Discussion	76
BIBLIOGRAPHY		78
APPENDIX A -	Calculation of the Linear Coefficient and Mortality Rates Used in the Health Benefit Estimation	85
APPENDIX B -	Vegetation Damage Class Modification.	92

Department of Economics. The authors also thank the reviewers who responded with thoughtful critiques to an earlier draft.

Ted Otis
John Duffield
Mike Ruby

PREFACE

This study of the costs and benefits of air pollution control illustrates the difficulty in performing such analyses. When the study was initially discussed, the Air Quality Bureau suggested an examination of the costs and benefits associated with each pollutant under study by the Montana Ambient Air Quality Standards Study. A preliminary review by the authors quickly revealed the detailed studies necessary to construct the dose-response functions required for benefit calculations simply had not been done for most pollutants. For some pollutants a dose-response function was available for a few items (e.g., the fading rate of vat-dyed cotton cloth) but for almost none of the other known effects of the pollutant. For others, data were available for major items (e.g., death rates) but the number of studies was very small and little confidence could be placed in their results. Sulfur dioxide was the only pollutant that had received sufficient research attention to allow benefit estimation for each of the major anticipated effects. Even for sulfur dioxide the available information is often unsatisfying and highly controversial. It has been possible to report some economic effects of fluoride pollution since several studies had been conducted in Montana, but a comprehensive analysis was not possible.

The authors express their appreciate for the guidance and support of the graduate faculty of the University of Montana

Corette Coal-fired Power Plant - The Montana Power Company's Corette Power Plant in Billings produces about 180 MW of electrical power. It burns low sulfur subbituminous coal from the strip mines at Colstrip. About seven percent of the sulfur in the coal is presently removed by crushing and air classification. This could be doubled to about 15 percent by a flotation process (Cavallaro et al. 1976). This coal-benefaction process also loses about 5 percent of the coal heating value. It would cost about $3 million to construct a coal cleaning facility and about $300,000 per year to operate it (including the value of the lost coal) (EPA 1978b).

There is not sufficient meteorological or monitoring information to know if the Corette plant contributes significantly to the high readings at some of the monitors in the Billings area. If additional control were necessary it would be possible to treat the exhaust gas stream in a lime scrubber to remove the sulfur dioxide. Based on the cost of a similar unit at the Colstrip power complex, the sulfur dioxide emissions could be reduced by about 30 percent for a capital expense of approximately $6.7 million and an annual operating cost of about $500,000. The costs of constructing a control facility within the already existing plant could increase the capital costs by as much as 50 percent, depending on the difficulties that are encountered. Because of the constraints of the site, it may be necessary to utilize holding tanks and a sludge dewatering facility before transferring the scrubber residue to tank trucks for transport to settling ponds. If water for the scrubber must be obtained

from an adjacent river, a clarifier may be necessary to clean the water before use in the scrubber. These items could add an additional $1.2 million in capital costs (Bloom et al. 1978).

Since the Lockwood ambient monitoring site averages less than 80 ug/m^3 sulfur dioxide, the Corette Power Plant, the Exxon and Conoco refineries, and Montana Sulphur and Chemical Company would require modifications only if the 50 ug/m^3 standard were enforced.

Exxon Petroleum Refinery - The Exxon Petroleum Refinery, along with the Corette Power Plant, is probably a significant contributor to the annual sulfur dioxide level of 77.2 ug/m^3 measured at the Lockwood School site. There is not sufficient meteorological or monitoring information to know which, if any, of the many stacks at the Exxon refinery do contribute significantly to this reading.

An approximate 30 percent decrease in sulfur dioxide emissions could be obtained by installing a wet gas scrubber on the coker-CO boiler exhaust stream. Exxon has estimated that this would require a capital expense of about $8.7 million in 1980 dollars and an annual operating cost of approximately $300,000 per year. Other means of reducing the sulfur dioxide emissions may be available to Exxon at less cost, e.g., treatment of sulfur-containing water or refinery fuel oil.

Conoco Petroleum Refinery - Despite comparative production capacity Conoco emits one third as much sulfur dioxide as each of the other two refineries, primarily because of the low sulfur

Canadian crude used by Conoco. The Conoco refinery does not appear to contribute significantly to elevated sulfur dioxide levels in the Billings area. It is not anticipated that additional controls would be required on this facility to achieve the 50 ug/m^3 standard. If additional controls are required, Conoco estimates that a stack scrubber at a capital cost of approximately $5 million (with operating costs of $400,000 per year) would be the most efficient approach.

Montana Sulphur and Chemical Company - The Montana Sulphur and Chemical Company is essentially one big air pollution control facility. It receives sulfur-laden natural gas and hydrogen sulfide from the Conoco and Exxon refineries. It removes sulfur from the gas and returns the clean gas to be burned in the refinery for the process heat. The hydrogen sulfide is converted to liquid hydrogen sulfide, sulfur, and other chemicals. In most refineries this plant would be an integral part of the refinery rather than a separately owned company.

Despite the sophisticated equipment, Montana Sulphur releases one of the most concentrated sulfur dioxide streams in the state. It recently decided to raise its exhaust stack to approximately 100 meters to increase dispersion. This is expected to cost approximately $700,000. There is not enough meteorological information to allow determination of how much sulfur dioxide Montana Sulphur is contributing to the high readings at the Lockwood site ambient monitor or if the increase stack height will reduce the ambient sulfur dioxide concentration.

The present emissions could be reduced to approximately one third their present levels with tail-gas cleaning equipment designed specifically for installations like Montana Sulphur. The capital cost for such equipment would be about $800,000. The annual operating costs of this unit would be approximately $200,000. Montana Sulphur believes that it would be necessary to have a second unit as a backup, doubling the capital costs.

ASARCO Lead Smelter - ASARCO recently completed the installation of a new sulfuric acid plant to control sulfur dioxide emissions from a portion of the lead sinter machine. They estimate that they have spent almost $40 million dollars on this control program. ASARCO also has announced plans to raise the height of the stack on its blast furnace. These modifications in ASARCO's operations are predicted to bring the sulfur dioxide emissions into compliance with both the 80 ug/m^3 and the 50 ug/m^3 standards. Because there have been no sustained periods of adverse weather conditions since the new acid plant began normal operation, it is not known if compliance with the standard actually will be achieved. If additional controls are required, it is not expected that substantial reconstruction of the smelter would be required.

ASARCO has rebuilt the lead sinter machine so that most of the sulfur dioxide gas generated is recirculated through the machine until it reaches a high enough concentration to be treated in the acid plant. This results in an overall control level for the plant of about 75 percent. One vent and a hood at the end

of the sinter machine are not recirculated; they are routed to the stack without any treatment for removal of sulfur dioxide. If additional control were required, emissions from the remaining vent could be recirculated through the sinter machine. This might raise the total control to 80 percent. This may not require any significant modifications to the sinter machine design or metallurgy; however, excess heat and particle loading generated by the recirculating process could require additional equipment.

ASARCO has developed an estimate of $6.2 million capital costs and $600,000 annual operating costs to modify the sinter machine to permit full recirculation. However, their calculations include many changes that are primarily for improvement in the operation of the sinter machine. Approximately one-third of the costs may be attributed to air pollution control requirements.

Summary of Control Costs

Table 16 provides a summary of the estimated control costs associated with compliance with the alternative 80 ug/m^3 and 50 ug/m^3 annual sulfur dioxide standards. Listed are estimates of the expenditures required for air pollution control equipment and installation and the annual operating and maintenance costs associated with the equipment.

In order to compare these control cost estimates with the estimated annual benefits, the equipment costs were annualized into equivalent annual values and added to the operating and maintenance costs. The annualization of capital expenditures

Table 16

Estimated Annual Air Pollution Control Costs Resulting from Alternative Ambient Sulfur Dioxide Standards

Industrial point source	80 ug/m^3 ($ millions) High est.	80 ug/m^3 ($ millions) Low est.	50 ug/m^3 ($ millions) High est.	50 ug/m^3 ($ millions) Low est.
Anaconda Copper Smelter	3.5	1.2	3.5	1.2
CENEX Petroleum Refinery	0.6	0.3	0.7	0.3
Corette Power Plant	0	0	1.8	0.5
Exxon Petroleum Refinery	0	0	1.3	0.8
Conoco Petroleum Refinery	0	0	1.1	0
Montana Sulphur and Chemical Company	0.1	0.1	0.7	0.1
ASARCO Lead Smelter	4.7	2.3	5.3	2.7

requires two values--a discount rate and a time period over which the capital costs is distributed. In general, the length of the time period and the average annual air pollution control costs are inversely related. A higher discount rate has the opposite effect: amortized costs will be greater. It was found that the true life of air pollution control equipment is probably bounded by 15 to 30 year time periods. For mixed public/private investments such as air pollution control, it was found that an appropriate discount rate is probably between four percent and eight percent.

Since the benefits are expressed in current dollars it is important to express the control costs in constant dollars. This requires the interest rate to be "inflation-free". For example, if the inflation rate is twelve percent and the interest rate is nine percent, then the inflation-free discount rate is a

negative 2.8 percent. Thus, a discount rate of four percent is a much higher rate than current experience would dictate and an eight percent rate is quite outrageous.

Due to the sensitivity of the resulting annualized costs to these parameters, the downward effect on control costs associated with use of the 30 year time period and four percent discount rate were used to generate the low estimate of control costs and the 15 year time period and eight percent rate were used for the high estimate.

Table 17 provides the estimated total annualized control costs associated with compliance with the 80 ug/m^3 and the 50 ug/m^3 ambient annual sulfur dioxide standards. Listed are totals for each area for the high and low estimates. An inspection of Table 17 reveals the sensitivity of the estimated annual control costs to the assumed annualization factors and the cost estimates

Table 17

Summary of Annual Control Costs Resulting from Alternative Sulfur Dioxide Standards in Montana

Area	80 ug/m^3 ($ millions) High est.*	Low est.+	50 ug/m^3 ($ millions) High est.*	Low est.+
Anaconda	3.5	1.2	3.5	1.2
Billings	0.7	0.3	5.6	1.7
Helena	4.7	2.3	5.3	2.7
TOTALS	8.5	4.2	14.4	5.6

* Annualized over 15 years at eight percent discount rate.

\+ Annualized over 30 years at four percent discount rate.

utilized. For example, the costs for the Corette Power Plant are assumed to be 3 million dollars capital and $300,000 operating for a coal beneficiation plant for the low estimate. This is annualized over 30 years with an interest rate of four percent, in constant dollars. This is an annual cost of about $475,000. For the high estimate, a scrubber at a cost of $11.2 million (including retrofit, clarifier, and sludge handling costs) is assumed with an eight percent interest rate over 15 years. This would raise the annual costs to $1.8 million. The change in the interest rate alone would increase the costs by a little more than 50 percent. The change in the anticipated project life increases the costs by an additional 50 percent. The change in the base estimate cost accounts for an increase of approximately 18% beyond this.

IV - SULFUR DIOXIDE: ANALYSIS AND DISCUSSION

The information developed in Chapters 2 and 3 is used in this Chapter to examine the economic case for alternative annual ambient sulfur dioxide standards and the resulting policy implications.

Analysis of Alternative Standards

Tables 13 and 14 (pp. 43 and 43) provide a summary of the benefits resulting from compliance with the NAAQS (80 ug/m^3) and present MAAQS (50 ug/m^3) sulfur dioxide standards. The estimated health, vegetation, materials, and visibility annual benefits resulting from compliance with an 80 ug/m^3 standard are between $2.0 and $6.2 million. The benefits resulting from compliance with a 50 ug/m^3 standard are between $2.9 and $10 million. The site specific benefits range from a low estimate of $400,000 for compliance with the 80 ug/m^3 standard in Helena to a high estimate of $7.1 million for the 50 ug/m^3 standard in Billings.

The variation in the high and low estimates is due to two factors: (1) alternative dose-response coefficients relating ambient sulfur dioxide to mortality rates (38 percent of the variation), and (2) the alternative values attached to the added risk of premature death (62 percent of the variation).

Table 17 (p. 61) provides a summary of the annual air pollution control costs associated with compliance with the alternative standards. The annual cost of achieving statewide compliance with an 80 ug/m^3 standard is estimated to be between $4.2 and $8.5 million; the annual cost is estimated to be between $5.6 and $14.4 million for the 50 ug/m^3 standard. The site specific costs for compliance with both standards range from a high estimate of $5.6 million annually in Billings to $1.2 million in Anaconda.

It is important to note that the costs include $40 million which have already been spent by ASARCO and $6 million which CENEX and Montana Sulphur are already committed to spend. These are included in the costs to make them consistent with the benefit calculations.

Table 18 provides the range of net benefits (costs) resulting from compliance with the alternative standards in Montana as well as each area. Evident from the table is the sensitivity of the

Table 18

Estimated Annual Net Benefits* Resulting from Alternative Ambient Sulfur Dioxide Standards in Montana

Area	80 ug/m^3 ($ millions)		50 ug/m^3 ($ millions)	
	High benefits low costs	Low benefits high costs	High benefits low costs	Low benefits high costs
Anaconda	$-0.1	$-2.7	$0.3	$-2.6
Billings	4.0	.1	5.4	-4.1
Helena	-1.5	-4.3	-1.3	-4.8
TOTALS	$ 2.4	$-6.9	$ 4.4	$-11.5

*A minus sign represents a net cost.

resulting net benefits to the acceptance of the low or high estimates of benefits and costs. If one were to accept the low estimate of benefits and high estimate of costs, the resulting total net costs would be $6.9 and $11.5 million for the 80 ug/m^3 and 50 ug/m^3 standards, respectively. That is, it would be a net loss to society. If one were alternatively to accept the high estimate of benefits and the low estimate of costs, the net social benefits would be $2.4 and $4.4 million for the 80 ug/m^3 and 50 ug/m^3 standards, respectively. The site specific annual net benefits (costs) range from $4.8 million in Anaconda (low benefits, high costs, and 50 ug/m^3) to $5.4 million in Billings (high benefits low costs, and 50 ug/m^3).

The incremental change in moving from the 80 ug/m^3 standard to the 50 ug/m^3 standard is the best measure of the net economic efficiency of meeting the state standard. The benefits will increase by between $900,000 and $3.8 million. The costs would increase by $1.4 million to $5.9 million. Thus the marginal change is approximately equal, suggesting that the economically optimal standard is in the vicinity of 50 ug/m^3.

The critical question is where the true benefits and costs lie in the low to high range of estimates. As previously stated, the range of estimated control benefits is due to alternative factors used in deriving the health benefits--the dose-response relationship and, primarily, the value assigned to reductions in the occurrence of premature death. The dose-response relationship between various air pollutants and health effects is of considerable debate. The primary argument against any relationship is that the statistical evidence fails to prove causality. Although this is true, it is

erroneous to dismiss the statistical evidence as spurious. Haveman (1979, p. 143), in his rather neutral review of the Lave and Seskin analysis, argues this point.

> While any individual estimate can be criticized (indeed, ridiculed), it is not possible to dismiss the persistence of positive and significant air pollution coefficients estimated with a wide variety of data and model specifications.

The estimates of health benefits were based on coefficients that do not include the effect of sulfates on mortality rates since sulfates are derived from sulfur dioxide. The true coefficient relating sulfur dioxide emissions to mortality rates may be higher than the high unadjusted coefficient used to derive the health benefits.

The magnitude of this underestimate can be judged by inspecting the equations reported in Tables A.1 and A.2 (pp. 88 and 89). The sum of the SO_2 and sulfate elasticities (when both pollutants are in the same equation) is about the same as when only one of the pollutants is included. Since the sulfate is derived from SO_2 it is plausible to assume that the average of the SO_2 elasticities, when sulfate is not in the equation, is the better high estimate. For the unadjusted this is a 4.83 percent elasticity (equations 7.9-5 and 7.9-7) or linear coefficients of about 1.33 and .96, respectively. These coefficients are 32 percent and 47 percent higher than the high and low used in the benefit calculations in this report.

On the other hand, Lave and Seskin have not corrected for possible bias due to omitted variables such as smoking habits. Haveman (1979, p. 143) points out this shortcoming.

> And while Lave and Seskin have addressed several of the estimation problems in their analysis, others remain. The absence of

> any control for differential smoking, nutritional, or health care usage patterns is a serious problem. To what extent are these patterns correlated with other socioeconomic variables or air pollution, hence, confounding the results?

The potential significance of the omitted variable bias is evident from inspecting the explanatory power of the adjusted regressions. The R^2 values range from .497, when only SO_2 is regressed on the adjusted mortality rates, to .728 when all five of the pollutants considered are included in the regression. This implies that 30 percent to 50 percent of the variation in mortality rates remain unexplained in specific regression sequences and could lead to an omitted variable bias.

The second point where alternatives were used to generate health benefits was the value assigned to reduced occurrence of premature death. The low estimate is based on the foregone earnings concept. The only argument for using this approach is that a person's ability to pay is constrained by their wealth--represented by foregone earnings.

There is no evidence, however, that there is any correlation between foregone earnings and the social disutility resulting from a premature death. Freeman (1979, p. 11) argues that

> The technique and estimating procedures must be based analytically and empirically on individual behavior and preference. . . . . Some measures of the value of reduced mortality have been based upon the earnings of affected individuals. Such measures do not meet this criterion, since there is no known relationship between willingness to pay on the one hand and earnings on the other. The most obvious limitation of the lost earnings measure is that it places no value on the lives of those who are not working because of their age, sex or other factors.

Although the foregone earnings concept is commonly used

in the literature (including Lave and Seskin), it represents nothing more than an arbitrarily chosen measure incorrectly used to represent the value of human life. There exists absolutely no connection between earnings potential and welfare, neither on an individual basis nor a collective basis.

On the other hand, it has been argued that the difference in age distribution between the susceptible population and Thaler and Rosen's (1976) relatively young occupational sample presents an upward bias when applying the risk aversion measures to air pollution induced mortaility. The rationale for this argument is that the Thaler and Rosen estimate approximates the value of a relatively young person's life while air pollution affects primarily the elderly and, perhaps, idle population that would value their lives less. This arguement can be rebutted on several grounds. First, Thaler and Rosen's occupational sample of industrial workers was not composed primarily of young people. The sample was distributed among all working ages. It measures the self-assigned value of any worker entering or leaving the occupation. Second, an inspection of Mendolsohn and Orcutt's (1978) predicted mortality rates reveals that not only old, retired people are subjected to premature death, but also middle-aged and younger populations.

The most convincing argument against the Thaler and Rosen risk aversion measures suggests that the measures are underestimates of the true value of reduced occurrence of premature death. Gregor (1977), p.59) argues that

> Thaler and Rosen's sample was composed of relatively risky occupations. Therefore, the individuals included in the sample

were relatively less risk averse than the general population. This downware bias coupled with the fact that these risk premiums only approximate the individual's own willingness to pay for risk reductions and not those of family, friends and society insure that any benefit estimates based on the Thaler and Rosen results will unequivocally represent a lower bound estimate.

In light of this argument and the lack of measurement of health benefits resulting from reduced levels of sulfate, the true health benefits probably are better represented by the high estimate.

Accepting the estimated vegetation and materials benefits as best estimates, one can also say that the rest of the benefits estimated are surely biased downward. Among the possibly substantial aesthetic and amenity damages unaccounted for in the analysis are soil erosion, disturbance to aquatic ecosystems, climatic variations, and the general irreversible imbalance imposed upon the natural environment. Thus it appears safe to conclude that a higher level of credence should be attached to the high estimates of total control benefits.

Whereas the control benefits are inherently biased downward, the control costs are inherently biased upward. Although very little can be added regarding the specific factors that lead to the high and low estimates of control costs (time period, discount rate, and acid neutralization), the control cost estimates, as a whole, warrant discussion.

Several factors usually result in inflated control cost estimates. Lave and Seskin (1978, p. 212) point out two such factors.

> The most common way of measuring the costs of abatement is to estimate the cost of adding devices that would reduce emissions from existing facilities. But adding an abatement device to an industrial

smokestack is often economically inefficient, since is may also decrease the operating efficiency of the firm. In the long-run, it is often more economical to construct a new plant designed to control emissions even if the initial investment is quite high. Furthermore, present cost estimates are usually based on current technology; at best, the analyst can make only educated guesses as to the effects of advancing technology. Because such guesses are subject to considerable uncertainty, they are seldom used in cost estimates. Consequently, cost estimates of pollution abatement are likely to be overestimated, since one expects major technological advances in the efficiency of control systems.

Atkinson and Lewis (1974)also found that the true least cost combination of control equipment among multiple point sources was much less costly than the sum of the estimated costs for each source. Although this is applicable only to areas with multiple sources such as Billings, it implies that it may be possible, based on a marginal analysis of each source, to achieve emission reductions at a fraction of the estimated cost by controlling the emissions from those sources where it is least costly.

Thus the true control costs possibly are best represented by the low estimate, but sufficient evidence is not available to confirm it. The true control costs associated with achieving compliance with the 80 ug/m^3 and 50 ug/m^3 standards remain obscure in light of the crudeness of the estimates and uncertainties about the technology.

This uncertainty regarding the true control costs associated with compliance with the alternative standards makes it impossible to ascertain the relevant true net benefits. Therefore, it is not possible to identify the preferred standard. The analysis does, however, reveal several policy implications discussed below.

Discussion of Policy Implications

The economic examination of alternative ambient sulfur dioxide standards revealed that substantial benefits would result from abatement of sulfur dioxide air pollution in Montana. The estimated annual benefits to health, vegetation, materials, and visibility resulting from compliance with the NAAQS 80 ug/m^3 annual standard and the proposed MAAQS 50 ug/m^3 standard are probably in excess of $6.2 and $10 million, respectively. These numbers assume the higher of two alternative dose-response coefficients for sulfur dioxide and the higher of two alternative dollar values for premature death. As discussed above, evidence from the literature suggests that the first premise is conservative, given the exclusion of benefits from reductions in sulfate-induced mortality. Accepting the latter premise is preferred, given that the higher value more nearly represents the full willingness-to-pay value associated with premature death.

Although these estimated benefits are substantial, the estimates of air pollution control costs associated with the alternative standards were found to be insufficiently refined to allow the selection of a preferred standard. The control costs required for compliance with the alternative standards are obscure in light of the limited knowledge concerning applicable technologies and the cost of those technologies.

In addition to the estimated benefits mentioned above, the analysis revealed several other policy implications. Whereas the cost of sulfur dioxide abatement in Montana was found to be dominated by money already spent at the ASARCO lead smelter, the benefits were found to be dominated by the urban Billings population. This illustrates the impact of the health values and the large population on the calculations.

The remaining major policy implication evident from the analysis is the shortage of data with which the analytical techniques available can select a preferred standard. Among the most critical information needs are sufficiently accurate data regarding ambient sulfate concentrations. Such sulfate data is necessary for any calculation with an increased confidence in the results. The state of Florida's economic analysis (SRI, 1978) of ambient sulfur oxide standards focused on the sulfate induced health and visibility effects. Despite the presence of sensitive citrus fruits and a high relative humidity, both vegetation, and material damages were found to be relatively negligible in light of the magnitude of the sulfate induced health and visibility benefits.

Given the availaibility of sufficient monitoring, a second need is for information on the dose-response relationship between the receptors and ambient concentrations of sulfur dioxide. Given the importance of natural environments in Montana, this is especially critical for all vegetation species (i.e., not only consumable agricultural crops).

The third and most limiting information shortage revealed by the analysis is on the cost side. The information currently available regarding abatement of sulfur dioxide is not sufficient to provide an economic basis for policy decisions.

=

V - FLUORIDES

Although fluoride pollution can have serious effects on the environment, there are relatively few sources of such pollution and these are located in only a few areas. For this reason, the EPA has not set a national ambient air fluoride standard, and the responsibility for regulation of fluoride pollution falls on state air pollution authorities.

The primary component of fluoride-induced economic loss is vegetation damage in the form of timber yield reduction and lost use of grazing land. As will be discussed below, damage to aesthetics, amenities, and private property is evident in Montana, but health and materials damage are not observed.

Another unique characteristic of fluorides is their accumulative nature. Primarily because of this property, "no damage functions exist" (Hershaft, et al., 1976). Without damage functions it is necessary to rely on site-specific studies. Several studies have looked into the effects of fluoride pollution at Montana's two primary sources. A Forest Service study (Carlson and Dewey, 1971) examined the area surrounding the Anaconda Company's aluminum plant near Columbia Falls while two studies by University of Montana students (Miles et al., 1978; vanHook, 1974) examined the Silver Bow valley near the Stauffer Chemical Company's phosphorous plant.

Anaconda Aluminum Plant

The Anaconda aluminum reduction plant (AAP) near Columbia Falls is the largest source of fluoride pollution in Montana. Averaged annually, the plant's fluoride emissions are approximately 2,500 pounds per day. In 1973, AAP petitioned the State of Montana for a variance from compliance with the State fluoride standards. The variance was granted and AAP was put on a compliance schedule to meet the state standard (Montana AQB, 1974). A second variance has been applied for to allow time for completion of a new air pollution control system. This system is to cost $30 million and is expected to reduce fluoride emissions to approximately 850 pounds a day. The new process is designed to capture about 8,000 tons of aluminum fluoride annually, resulting in an annual savings (net of operating costs) of $4.2 million to the Anaconda Company (Montana AQB, 1974; Ponder and Gerstle, 1974; Jon Bolstad, personal communication, 1978). A further reduction to 400 pounds per day could be achieved by adding roof monitor scrubbers and peripheral equipment. The total capital cost of such a system might exceed $25 million with no significant resource recovery expected (Montana AQB, 1974; EPA, 1978c; Jon Bolstad, personal communication, 1978).

During the period 1968 to 1977, AAP's fluoride emissions are estimated to have resulted in the direct loss of 10.75 million boardfeet (MMBF) of commercial timber on 13,000 acres of Flathead National Forest (Carlson, 1978b). Another 16.12 MMBF of yield reduction on 19,000 acres of private and state lands can be attributed to AAP emissions.[8] Assuming an equal amount of yield reduction occurs annually, fluoride emissions from AAP can be

[8]According to Carlson, each isopol contains about a 40/60 split of National Forest to private timber.

estimated to have resulted in a loss of 2.69 MMBF/year. A stumpage value for this loss was estimated from the Forest Service's Flathead National Forest Summary of Timber Sales (1977, 1978). The stumpage values vary considerably during the year, so annual averages were calculated and a weighted average of the nine affected species was computed. This produced an average value of $61 per thousand boardfeet (MBF). Thus the annual loss is estimated at $164,000. No attempt was made to measure the synergistic effect of fluorides and insects on timber, although the Forest Service considers its potential impact significant (Carlson and Hammer, 1974).

Litigation records were reviewed to provide another estimate of the damage to the property of private residences near AAP. Damages sought by the plaintiffs residing near the AAP facility were based upon expert appraisal of lost timber yield, potential subdividing loss, recreational losses, general aesthetic losses, and, in one case, health costs. Leonard (1970) argues that it is the awarded damages less trial costs that represent the economic loss, although the plaintiffs generally feel the entire damages sought are justified.

Several cases involving fluoride-induced damages from AAP have been concluded at this time, although all have been settled out of court.[9] The plaintiffs initially sought damages in excess of $3 million. In one instance the settlement included total acquisition of the land by AAP as well as settlement of a claim

[9]The release of specifics regarding legal matters settled out of court is a delicate situation. Consultation with the attorneys representing each party gave the information reported here.

for personal injury. The remaining cases were strictly for damages to the property, without acquisition. The economic loss to the property is the difference between the present fair market value and what the fair market value would be in the absence of the influence of AAP. The average loss for the cases that have been settled is approximately $30 per acre. These properties are each about four miles from AAP.

Glacier National Park is six miles northeast of AAP. Each morning prevailing winds sweep the night's buildup of fluorides over the saddle of Teakettle Mountain and onto the forests in the Park. About 76,670 acres of the Park have been subjected to elevated levels of fluorides (Carlson and Dewey, 1971). A site as far away as the northeast end of Lake McDonald has recorded elevated levels of fluoride (Hall, 1978). To the extent that these exposures cause an observable (over the long-term) change in the vegetation and wildlife in the park there will be lost economic values to citizens who value preservation of natural environments and to those who visit Glacier National Park or hope to do so in the future. Estimates of this value can be made by several techniques, but all are time consuming. Since the present control program is expected to eliminate the damage to Glacier National Park, these estimates have not been made.

Carlson (1978) estimates that at fluoride emission levels of 500 to 1,000 lbs/day the affected properties would be limited to within three to four miles of AAP. Thus the present control program should eliminate the damage to Glacier National Park, reduce the timber loss by more than one-half, and limit the private

property damage to about 3,000 acres. Regardless of the value associated with this reduction in damages, an emission reduction to 850 lbs/day will result in net social benefits since the value of recovered production materials and reduced consumption of electricity by the new system more than offsets the investment in pollution control.

Stauffer Chemical Company

Violations of the existing 1 ppb 24-hour fluoride ambient air quality standard have been recorded near the Stauffer Chemical Company's (SCC) elemental phosphorous plant near Ramsay. Fluoride emissions are currently estimated to be about 340 lbs/day. The primary uncontrolled source of fluoride emissions is the slag tapping operations of the electric furnace. A control program now nearing completion is expected to reduce emissions from the cooling slag by immediately smothering it under water. This slag granulation facility is estimated to cost about $1.2 million.

Several studies (Miles et al., 1978; VanHook, 1974; AQB monitoring files) have documented the fluoride content of various plant and animal species in all directions from SCC. Data for September, 1977 show approximately 130,000 acres of agricultural land with vegetation containing elevated concentrations of fluorides. Some 65,000 acres showed concentrations greater than 30 ug/g (ug of fluoride/g of plant). 42,000 acres contain vegetation with fluoride levels greater than 35 ug/g and 30,000 acres contain forage with fluoride content greater than 40 ug/g. Miles et al. said that cattle were being damaged "even in areas where fluoride levels in forage were found to be below State standards (35 ug/g)." This

would imply that at least 42,000 acres of potential grazing land in the Ramsay area is significantly reduced in economic value by SCC fluoride emissions.

In order to estimate the economic loss from pollution it is necessary to know the potential productivity of the land. The Silver Bow County Extension Office estimated, and the Soil Conservation Service confirmed, that the area's potential for alfalfa should be roughly equivalent to the county average yield of 2.27 tons per acre (David Dickens, personal communication, 1978; Ray McPhail, personal communication, 1978; Montana Department of Agriculture, 1976).

At $40 per ton, each acre could produce $90.80 woth of alfalfa yearly. Assuming a net income at 27.4 percent of gross sales,[3] the net annual income per acre would be $24.66. When this lost opportunity cost is applied to the estimated 42,000 acres affected by fluoride emissions, lost annual income is valued at between $3.8 million (gross) and $1 million (net).

The estimate of lost productivity due to pollution is equal to the lost alfalfa returns only if the land, with fluoride fumigation, has no other economically significant use. This appears to be the case. Further area-specific analysis of net returns, market prices of land, and alternative uses could improve the estimate of the value of lost production.

The current control program is expected to reduce emissions to about 110 lbs/day and limit SCC impact to not more than 12,000 acres (Turner, 1970). The benefit of such reduction would be the

[3]U.S. farm average of net to gross for 1974.

avoided crop destruction on 30,000 acres. Using the damage estimate per acre derived above, the potential annual benefit is $2.7 million (gross) or $700,000 (net). A further reduction of fluoride emissions to approximately 70 lbs/day might be achieved by doubling the capacity of the present furnace hood evacuation system and extending its area of coverage at an additional cost of less than $2 million, resulting in a significant fluoride impact on less than 7,000 acres. The potential benefits of this incremental reduction, in terms of alfalfa production alone, is the use of another 5,000 acres, or an annual benefit of $500,000 (gross) or $100,000 (net).

Analysis and Discussion

The current control programs at both the Anaconda Aluminum facility in Columbia Falls and the Stauffer Chemical Company's plant in Ramsay are expected to end violations of the existing Montana 24-hour air quality standard for fluorides. It is not known if the longer-term or forage standards also will be met.

Incomplete information on the environmental and economic effects of these two sources prevents any substantial conclusions from being drawn from the analysis presented here. The data presented clearly indicate that the present control programs are justified solely on economic efficiency arguments. At Anaconda Aluminum the recovery of valuable process materials will more than compensate for the cost of control. At Stauffer Chemical's phosphorous plant the annualized cost of the slag granulation facility is much less than the estimated gain in crop yields expected as the soils recover. Conversely, the estimated cost of

further controls at AAC cannot be justified by the anticipated reduction in economic damages. Although the cost estimate is quite crude, it is very doubtful that a detailed analysis would reduce it to a range comparable to the estimated damages. The estimated cost of further SCC controls is equally uncertain. Sufficient engineering detail is not available to permit a more precise estimate and possible maintenance and operating costs are not known. In this instance, a more detailed evaluation might reduce the final annualized estimate to a rough equality with the estimated environmental costs. At the present stage of evaluation, it is not possible to say what the economic analysis implies for further control at SCC.

BIBLIOGRAPHY

Asmus, Barry E., and Richard Stroup. Air Pollution Control Economics: The Case of SO_2 Emissions from a Montana Smelter. Research Report No. 24. Bozeman, Montana: Agriculture Experiment Station, 1972.

Atkinson, Scott E. and Donald H. Lewis. "A Cost-effectiveness Analysis of Alternative Air Quality Control Strategies," Journal of Environmental Economics and Management[1] (1974), 237-250.

Benedict, Harris, M., C. J. Miller, and J. S. Smith. Assessment of Economic Impact of Air Pollution on Vegetation in the United States: 1969-1971. EPA 650/5-73-002 Environmental Protection Agency, 1973.

Blank, F. M., David Brookshire, T. D. Crocker, R. C. D'Arge, Robert Horst, and R. D. Rowe. Valuation of Aesthetics Preferences: A Case Study of Economic Value of Visibility. Palo Alto, California: Electric Power Research Institute, 1977.

Bloom, S. G., H. S. Rosenberg, D. W. Hissing, and J. H. Oxley. Analysis of Variations in Costs of EGD Systems. Palo Alto, California: Electric Power Research Institute, 1978.

Brookshire, D. S., B. C. Ives, and W. D. Schulze. "The Valuation of Aesthetic Preferences," Journal of Environmental Economics and Management 3 (1976), 325-346.

Carlson, Clinton E. Letter to David Maughan, Montana Department of Health and Environmental Sciences, April 7, 1978a.

Carlson C. E., Fluoride Induced Impact on a Coniferous Forest Near the Anaconda Aluminum Plant in Northwestern Montana. Unpublished Ph.D. dissertation, University of Montana, 1978b.

Carlson, Clinton E. and J. E. Dewey. Environmental Pollution by Fluorides in Flathead National Forest and Glacier National Park. Report for Division of State and Private Forestry, Forest Insect and Disease Branch, Washington, D.C: U.S. Department of Agriculture, 1971.

Carlson, Clinton E. and W. Hammer. Impact of Fluorides and Insects on Radial Growth of Lodgepole Pine Near the Aluminum Smelter in Northwestern Montana. Forest Service Research Paper. Missoula, Montana: U. S. Department of Agriculture; Northern Region, 1974.

Carlson, Clinton E., M.D. McGregor, and N. M. Davis. Sulfur Damage to Douglas Fir Near a Pulp and Paper Mill in Western Montana. Forest Service Research Paper. Missoula, Montana: U. S. Department of Agriculture, Northern Region, 1974.

Cavallaro, J. A., M. T. Joynston, and A. W. Deurbrouck. Sulfur Reduction Potential of U. S. Coals. EPA 600/2-76-091. Environmental Protection Agency, 1976.

Cooper, B. S. and D. P. Rice. "The Economic Cost of Illness Revisited," Social Security Bulletin 39 (February, 1976), 21-36.

Feliciano, A. 1971 Survey and Assessment of Air Pollution Damage to Vegetation in New Jersey. Contract No. 68-02-0078. Environmental Protection Agency, 1972.

Ferejohn, J. and T. Page. "On the Foundations of Intertemporal Choice," American Journal of Agricultural Economics 60 (1979), 269-275.

Fink, F. W., F. H. Buttner, and W. K. Boyd. Technical Economic Evaluation of Air Pollution Corrosion Costs on Metals in the U.S. Columbis, Ohio: Battelle Memorial Institute, 1971.

Freeman, A. Myrick. The Benefits of Environmental Improvement. Baltimore, Maryland: Johns Hopkins University Press, 1979.

Gelhaus, J. W., J. Schneider, and M. D. Roach. Annual Air Quality Data Summary for Montana 1977. Helena, Montana: Air Quality Bureau, Department of Health and Environmental Sciences, 1978.

Gillette, Donald G. "Sulfur Dioxide and Material Damage." Journal of Air Pollution Control Association 25 (1975), 1238-1243.

Gillette, Donald G. and James B. Upham. Material Damage from SO_2: A Reassessment. EPA-650/9-73-009. Environmental Protection Agency, 1973.

Green, Alan W. and Theodore S. Setzer. The Rocky Mountain Timber Situation, 1970. USDA Forest Service Resource Bulletin Int-10. Ogden, Utah: Intermountain Forest and Range Experiment Station, 1974.

Gregor, John J. Intra-urban Mortality and Air Quality: An Economic Analysis of the Costs of Pollution Induced Mortality. EPA 600/5-77-009. Environmental Protection Agency, July, 1977.

Guderian, R. Air Pollution: Phytotoxicity of Acidic Gases and its Significance. New York: Springer Verlag, C. Jeffrey Brandt, trans. 1977.

Hall, Robert. The Status of Fluoride Pollutants in Glacier National Park, U. S. National Park Service. 1978.

Haveman, Robert H. "Review of Air Pollution and Human Health by Lester B. Lave and Eugene P. Seskin," Journal of Economic Literature 17 (1979), 141-143.

Haynie, F. H., J. W. Spence, and J. B. Upham. Effects of Gaseous Pollutants on Materials--A Chamber Study. EPA-600/3-76-015. Environmental Protection Agency, 1976.

Haynie, F. H. and J. B. Upham. "Effects of Atmospheric Sulfur Dioxide on the Corrosion of Zinc," Materials Protection and Performance 9 (1970), 35-40.

Heck, W. W. "Plants and Microorganisms." In Ozone and Photochemical Oxidants. EPA-600/1-76-027. Environmental Protection Agency, 1976.

Hershaft, A. , J. Morton and G. Shea. Critical Review of Air Pollution Dose-effect Functions. Contract No. EQ5-AC012. Washington, D.C.: Council on Environmental Quality, 1976.

Husar, R. B., D. E. Patterson, J. D. Musar, N. V. Gillan. "Sulfur Budget of a Power Plant Plume." Atmospheric Environment 12 (1978): 549-68 (1978).

Jansson, Eric. National Estimate of the Damage to Vegetation by Air Pollution. Rockville, Maryland: EnviroControl Incorporated, March, 1975.

Lacasse, N. L. Assessment of Air Pollution Damage to Vegetation in Pennsylvania, June 1970-1971. University Park, Pennsylvania: Center for Air Environmental Studies, 1971.

* Latimer, D. A., R. W. Bergstrom, S. R. Hayes, M. Liu, J. H. Seinfeld, G. Z. Whitten, M. A. Wojcik, and M. J. Hillyer. The Development of Mathematical Models for the Prediction of Anthropogenic Visibility Impairment. San Rafael, California: Systems Applications, Inc., 1978.

Lave, Lester B. and Eugene P. Seskin. Air Pollution and Human Health. Baltimore, Maryland: Johns Hopkins University Press, 1977.

* Leung, Steve, W. Reed, S. Cauchois, R. Howitt and R. Oshima. Economic Techniques for the Valuation of Agricultural Crop Yields: A Review and Evaluation of Methodologies. EPA 600/5-78-018 Environmental Protection Agency, 1977.

* Liu, Ben-Chieh and Eden Siu-humg Yu. Physical and Economic Damage Functions for Air Pollutants by Receptors. EPA-600/5-76-001. Environmental Protection Agency, 1976.

Materna, J. Criteria for Characterization of Pollution Damages in Forests. Proceedings of the Third International Clean Air Congress. Dusseldorf, West Germany, 1973, pp. A121-A123.

Mendolsohn, Robert and Guy Orcutt. An Empirical Analysis of Air Pollution Dose Response Curves. Working Paper No. 800. New Haven: Connecticut: Institute for Social and Policy Studies, Yale University, 1978.

Middleton, J. T., E. F. Darley and R. F. Brewer. "Damage to Vegetation from Polluted Atmosphere," Journal of the Air Pollution Control Association 8 (1958), 9-15.

Miles, J. A. G. D. Bissell, and K. J. Zachheim. Ramsey, Montana 1978: 22 Years of Fluoride Pollution. Environmental Studies Laboratory, University of Montana, Missoula, Montana 1978.

Millecan, A. A. A Survey and Assessment of Air Pollution Damage to California Vegetation. California Department of Agriculture, 1971.

_____. A Survey and Assessment of Air Pollution Damage to California Vegetation, 1970 through 1974. California Department of Agriculture, 1976.

Montana Air Quality Bureau. EIS for the Air Pollution Variance Requested by the Anaconda Aluminum Company for its Aluminum Reduction Plant at Columbia Falls, Montana, 1974.

Montana. Department of Agriculture. Montana Agriculture Statistics: County Statistics 1974 and 1975. Vol. XVI. Helena, Montana: State of Montana, 1976.

Montana. Department of Community Affairs. Montana Population Projections, 1975-2000. Helena, Montana: State of Montana, 1977.

Naegle, J. A., W. A. Feder, and C. J. Brandt. Assessment of Air Pollution Damage to Vegetation in New England: June 1971-July 1972. Contract No. RS-72-009. Environmental Protection Agency, 1972.

Newman L., J. Forrest, and B. Manowitz. The application of an isotopic ratio technique to a study of the atmospheric oxidation of sulfur dioxide in the plume from an oil-fired power plant. Atmospheric Environment 9 (1975), 959-68.

Pell, E. J. 1972 Survey and Assessment of Air Pollution Damage to Vegetation in New Jersey. Contract No. RS-73-022. Environmental Protection Agency, 1973.

Ponder, Thomas C. and Richard W. Gerstle. Particulate and Fluoride Emissions Control, Anaconda Aluminum Company, Columbia Falls, Montana. Cincinnati: Environmental Protection Agency, 1974.

Randall, A., O. B. Ives, and E. Eastman. "Bidding Games for Valuation of Aesthetic Environmental Informants," Journal of Environmental Economics and Management1(1974), 132-149.

Salmon, R. L., Systems Analysis of the Effects of Air Pollution in Materials, Midwest Research Institute. Contract No. 22-69-113. National Air Pollution Control Administration, 1970.

Scheffer, Theodore C. and George G. Hedgcock. Injury to Northwestern Forest Trees by Sulfur Dioxide from Smelters. Technical Bulletin No. 1117. U. S. Department of Agriculture, 1955.

Schweitzer, Dennis L., Robert E. Benson, and Richard J. McConner. Description Analysis of Montana's Forest Resources. USDA Forest Service Resource Bulletin. Ogden, Utah: Intermountain Forest and Range Experiment Station, 1975.

Schwing, Richard C. and Gary C, McDonald. "Measures of Association of Some Air Pollutants, Natural Ionizing Radiation, and Cigarette Smoking with Mortality Dates," The Science of the Total Environment 5 (1976): 139-69.

Seskin, Eugene. Letter to Martin Perga, CENEX, Laurel, Montana, February 15, 1979.

Spence, J. W. and F. H. Haynie. Paint Technology and Air Pollution: A Survey and Economic Assessment. AP-103. Environmental Protection Agency, 1972.

SRI International. Florida Utility Pollution Control Options and Economic Analysis. 2 vols. Florida Sulfur Oxide Studies, 1978.

Thaler, R. and S. Rosen. "The Value of Saving a Life: Evidence from the Labor Market," Household Production and Consumption, ed. N. Terleckyj. New York, New York: National Bureau of Economic Research, 1976.

U. S. Department of Agriculture. Forest Service. Summary Report of Timber Sales. Missoula, Montana: Northern Region, 1977-78.

U. S. Department of Commerce. Bureau of the Census. Census of Population: 1970 General Population Characteristics. 1971.

_____. Statistical Abstract of the United States: 1975. 1975.

U. S. Department of Commerce. National Oceanic and Atmosphere Administration. Local Climatological Data. Billings, Montana: 1977.

U. S. Department of Health, Education and Welfare. Vital Statistics of the United States, 1969. 1972.

_____. Vital Statistics of the United States, 1970. 1973.

_____. Vital Statistics of the United States, 1971. 1974.

U. S. Department of Interior. National Park Service. Analysis of Kaiparowits Power Plant Impacts on National Recreation Resources. Denver, Colorado: Denver Service Center, 1976.

U. S. Department of Labor. Bureau of Labor Statistics. Monthly Review. 1977.

U. S. Environmental Protection Agency. Effects of Sulfur Oxides in the Atmosphere on Vegetation--Revised Chapter for "Air Quality Criteria for Sulfur Oxides." EPA R3-73-030. 1973.

_____. The Bioenvironmental Impact of a Coal-fired Power Plant. Fourth Interim Report. EPA 600/3-78-021, 1978a.

_____. Particulate and Sulfur Dioxide Emission Control Costs for Large Coal-fired Boilers. Report No. EPA-450/3-78-007. 1978b.

_____. Guideline Document: Control of Fluoride from Emissions from Existing Primary Aluminum Plants, 1978c.

U. S. House of Representatives. Committee on Interstate and Foreign Commerce. Clean Air Act Amendments of 1977. Report No. 95-294. 1977.

Vars, R. C. and G. W. Sorenson. Study of the Economic Effects of Changes in Air Quality. Report No. EPA-7-117. Corvallis, Oregon: Air Resources Center, Oregon State University, June, 1972.

VanHook, C. "Fluoride Distribution in the Silver Bow, Montana, Area." Fluoride 7 (1974):181-199

Waddell, Thomas. The Economic Damages of Air Pollution. EPA-600/5-74-012. Environmental Research Center, 1974.

Waggoner, Alan and Robert Charlson. Aerosol Characteristics and Visibility. EPA-600/3-77-072. Environmental Protection Agency, 1977.

Weidensaul, T. C. and N. L. Lacasse. Statewide Survey of Air Pollution Damage to Vegetation--1969. University Park, Pennsylvania: Center for Air Environmental Studies, Pennsylvania State University, 1970.

Wilhour, Raymond G., Grady E. Neely, David E. Weber, and Louis Grouthaus. Response of Selected Small Grains, Native Range Grasses and Alfalfa to Sulfur Dioxide. Corvallis, Oregon: Environmental Protection Agency, Corvallis Environmental Research Laboratory, 1978.

Williams, Wayne T. Effects on Plants of Sulfur Pollutants from Coal Combustion. San Francisco, California: Citizens for a Better Environment, 1978.

Wilson, W. E., R. J. Charlson, R. J. Husar, K. T. Whitby, and D. Blumenthal. Sulfates in the Atmosphere. EPA-600/7-77-021. Environmental Protection Agency, 1977.

Yocom, J. E. and N. Grappone. Effects of Power Plant Emissions on Materials. Palo Alta, California: Electric Power Research Institute, 1976.

Zimmerman, P. W. Chemicals Involved in Air Pollution and Their Effect Upon Vegetation. Professional Paper No. 2. Yonkers, New York: Boyce Thompson Institute, 1955.

APPENDIX A

CALCULATION OF THE LINEAR COEFFICIENTS AND MORTALITY ATES USED IN THE HEALTH BENEFIT ESTIMATION

This appendix provides an examination of the Lave and Seskin regression results and the two linear coefficients and mortality rates used in deriving the high and low estimates of health benefits. Tables A.1 through A.3 provide the Lave and Seskin multiple regression results and the definition, mean value, and standard deviation of the variables used. The rationale and procedure for adjusting the mortality rates are detailed in Appendix 3 of Lave and Seskin (1977).

As evident from a comparison of Tables A.1 and A.2, the statistical properties of the sulfur dioxide coefficients of the unadjusted regression are superior to those from the adjusted regression. Whereas only one of the four mean sulfur dioxide coefficients of the adjusted regression are significant at the 10 percent level, three of the four coefficients of the unadjusted regression are significant at the 10 percent level, and the fourth is significant at the 15 percent level. An inspection of all of the sulfur dioxide coefficients reveals that the minimum and mean readings are generally significant. The maximum sulfur dioxide coefficients are all negative and, in one case (equation 7.9-9), it is significantly negative. This is not surprising, however, considering the variation in maximum readings observed (see Table A.3).

The lower R^2 values associated with the adjusted regression reflect the loss of explanatory power caused by differences in the age-race make-up of the population. They also reflect the lower variation in mortality rates caused by the adjustment procedure (See Table A.3).

Another major point, evident from the regression results, is the effect on the sulfur dioxide elasticities when sulfate is added to the regression, e.g., the sum of the SO_2 elasticities for equation 7.8-7 (SO_2 and P regressed on mortality) of .0417 percent is reduced to .0281 percent (equation 7.8-9) when SO_4 is added to the regression. The implications of this are discussed in Chapter 4. This indicates that a relatively substantial effect on mortality is achieved by reducing ambient sulfate--a derivative of sulfur dioxide. The result could be a substantial underestimate in health benefits by using an average of the sum of the SO_2 elasticities rather than the one sum of the SO_2 elasticities derived from equation 7.8-5. Ideally, one should consider the effect of decreased sulfate resulting from reductions in sulfur dioxide emissions.

The linear coefficients used to derive a health benefit were derived by averaging the sums of the SO_2 elasticities from each of the two sets of four equations.[1] The average of the unadjusted sum of the SO_2 elasticities is .0366 percent; the adjusted is .0232 percent. By definition these elasticities measure the percent

[1] This procedure was suggested by Eugene Seskin (letter to Martin Perga, CENEX, 15 February 1979).

Table A.1

Unadjusted Total Mortality Rates (the Effects of Additional Air Pollutants), 1969

	7.8-1	7.8-2	7.8-3	7.8-4	7.8-5	7.8-6	7.8-7	7.8-8	7.8-9	7.8-10
R^2	.848	.842	.792	.815	.843	.869	.875	.915	.914	.924
Constant	570.798	567.612	526.489	753.474	702.037	612.791	699.055	743.408	675.191	808.081
Air pollution variables										
Min S	−.821					−1.201		−1.761	−1.834	−1.949
	(−1.44)					(−2.08)		(−3.26)	(−3.40)	(−3.61)
Mean S	1.116					1.098		1.142	1.061	1.030
	(3.48)					(3.21)		(3.51)	(3.28)	(3.18)
Max S	−.080					−.124		−.132	−.092	−.101
	(−.91)					(−1.40)		(−1.67)	(−1.15)	(−1.28)
Sum S elasticities	8.51					5.47		3.61	3.58	2.45
Min P		.230				.019	.259	−.300	.140	−.103
		(.35)				(.03)	(.40)	(−.51)	(.22)	(−.16)
Mean P		.656				.044	.314	.018	−.010	−.145
		(1.69)				(.10)	(.79)	(.05)	(−.02)	(−.35)
Max P		.136				.153	.139	.223	.181	.226
		(2.00)				(2.34)	(2.02)	(3.79)	(2.73)	(3.37)
Sum P elasticities		12.00				5.07	8.47	5.71	5.74	4.71
Min NO_x			2.478					2.027	−.031	1.245
			(.63)					(.66)	(−.01)	(.41)
Mean NO_x			−.509					−1.395	−.203	−.746
			(−.31)					(−1.12)	(−.16)	(−.59)
Max NO_x			−.290					−.463	−.507	−.464
			(−.76)					(−1.64)	(−1.77)	(−1.66)
Sum NO_x elasticities			−1.98					−5.48	−3.93	−4.32
Min NO_2				−.853				−.317		−.376
				(−1.97)				(−.91)		(−1.10)
Mean NO_2				.994				.674		.553
				(2.60)				(2.13)		(1.76)
Max NO_2				−.141				−.008		−.007
				(−.94)				(−.07)		(−.06)
Sum NO_2 elasticities				6.72				8.45		6.41
Min SO_3					5.973		3.703		2.749	1.709
					(2.66)		(1.62)		(1.31)	(.80)
Mean SO_3					1.134		1.188		1.397	1.158
					(1.49)		(1.66)		(2.08)	(1.76)
Max SO_3					−1.27		−.156		−.285	−.227
					(−.60)		(−.80)		(−1.51)	(−1.23)
Sum SO_3 elasticities					5.48		4.17		2.81	2.16
Socioeconomic variables										
P/M²	.151	.162	.136	.153	.168	.171	.170	.156	.178	.172
	(3.28)	(3.42)	(2.55)	(2.82)	(3.56)	(3.75)	(3.73)	(3.67)	(4.34)	(4.03)
≥65	5.616	6.172	5.998	6.167	5.677	5.767	5.887	5.845	5.456	5.700
	(14.70)	(16.34)	(13.55)	(14.74)	(14.87)	(15.44)	(16.55)	(16.47)	(16.21)	(16.16)
NW	.488	.575	.484	.526	.493	.584	.535	.605	.525	.589
	(4.02)	(4.80)	(3.46)	(3.99)	(4.15)	(4.81)	(4.81)	(5.44)	(4.70)	(5.21)
Poor	−.035	−.134	.034	.062	.199	−.207	.088	−.090	−.057	−.045
	(−.11)	(−.43)	(.09)	(.18)	(.62)	(−.67)	(.30)	(−.33)	(−.21)	(−.17)
Sum SE elasticities	64.33	70.28	68.60	71.34	67.46	65.77	69.11	67.82	63.34	66.75
Log Pop	−.552	−.693	−.380	−.945	−.777	−.678	−.909	−.960	−.710	−1.039
	(−2.30)	(−2.88)	(−1.30)	(−3.06)	(−3.06)	(−2.87)	(−3.85)	(−3.66)	(−2.97)	(−3.88)

Note All regressions are based on data for sixty-nine SMSAs (see table C 1, pp. 317-320). The numbers in parentheses below the regression coefficients are *t* statistics.

Source: Lester B. Lave and Eugene P. Seskin, Air Pollution and Human Health (Baltimore: Johns Hopkins University Press for Resources of the Future, 1977), pp. 146-147. Reprinted by permission.

Table A.2

Age-Sex-Race-adjusted Total Mortality Rates (the Effects of Additional Air Pollutants), 1969

	7.9-1	7.9-2	7.9-3	7.9-4	7.9-5	7.9-6	7.9-7	7.9-8	7.9-9	7.9-10
R^2	.516	.531	.355	.434	.497	.594	.607	.689	.702	.728
Constant	1067.027	1057.043	1014.537	1205.630	1166.708	1102.833	1154.284	1193.226	1110.729	1205.511
Air pollution variables										
Min S	−.761					−1.062		−1.486	−1.466	−1.501
	(−1.45)					(−2.03)		(−2.80)	(−2.85)	(−2.85)
Mean S	.979					.889		.901	.920	.827
	(3.32)					(2.87)		(2.82)	(2.98)	(2.62)
Max S	−.078					−.118		−.122	−.094	−.082
	(−.96)					(−1.48)		(−1.56)	(−1.23)	(−1.06)
Sum S elasticities	6.71					3.33		1.84	2.98	2.08
Min P		.298				.094	.086	−.201	−.134	−.281
		(.52)				(.16)	(.14)	(−.34)	(−.22)	(−.45)
Mean P		.604				.182	.516	.155	.317	.218
		(1.76)				(.46)	(1.43)	(.41)	(.78)	(.54)
Max P		.126				.142	.099	.187	.120	.143
		(2.09)				(2.40)	(1.58)	(3.24)	(1.90)	(2.19)
Sum P elasticities		10.78				6.19	8.42	6.17	6.20	5.32
Min NO_x			3.156					2.400	1.362	1.865
			(.89)					(.80)	(.47)	(.64)
Mean NO_x			−.998					−1.486	−1.065	−1.134
			(−.68)					(−1.21)	(−.89)	(−.92)
Max NO_x			−.030					−.212	−.263	−.269
			(−.09)					(−.76)	(−.96)	(−.99)
Sum NO_x elasticities			−1.00					−3.61	−3.47	−3.43
Min NO_x				−.888				−.417		−.522
				(−2.27)				(−1.22)		(−1.57)
Mean NO_x				.923				.658		.544
				(2.69)				(2.12)		(1.78)
Max NO_x				−.170				−.066		−.071
				(−1.26)				(−.58)		(−.64)
Sum NO_x elasticities				4.40				5.64		3.45
Min SO_x					6.201		4.329		3.548	3.141
					(3.00)		(2.09)		(1.77)	(1.52)
Mean SO_x					.978		.963		1.079	.976
					(1.39)		(1.48)		(1.68)	(1.52)
Max SO_x					−.194		−.225		−.335	−.319
					(−.99)		(−1.27)		(−1.85)	(−1.77)
Sum SO_x elasticities					3.95		2.64		1.35	.99
Socioeconomic variables										
P/M²	.110	.118	.100	.117	.133	.129	.139	.126	.146	.150
	(2.61)	(2.81)	(2.08)	(2.39)	(3.08)	(3.12)	(3.36)	(3.01)	(3.711)	(3.60)
≥65	−.295	.198	.087	.143	−.194	−.119	−.004	−.047	−.354	−.206
	(−.84)	(.59)	(.22)	(.38)	(−.55)	(−.35)	(−.01)	(−.13)	(−1.10)	(−.60)
NW	.329	.399	.334	.337	.335	.424	.377	.431	.364	.385
	(2.95)	(3.75)	(2.64)	(2.84)	(3.06)	(3.85)	(3.73)	(3.94)	(3.42)	(3.49)
Poor	.167	.088	.229	.260	.320	−.007	.195	.087	.084	.095
	(.57)	(.31)	(.69)	(.84)	(1.08)	(−.03)	(.72)	(.33)	(.32)	(.37)
Sum SE elasticities	4.30	9.27	8.46	9.47	6.97	5.84	8.26	7.46	3.81	5.64
Log Pop	−.363	−.494	−.215	−.646	−.532	−.496	−.648	−.685	−.436	−.649
	(−1.65)	(−2.32)	(−.81)	(−2.32)	(−2.27)	(−2.32)	(−3.01)	(−2.65)	(−1.91)	(−2.48)

Note. All regressions are based on data for sixty-nine SMSAs. The numbers in parentheses below the regression coefficients are *t* statistics.

Source: Lester B. Lave and Eugene P. Seskin, Air Pollution and Human Health (Baltimore: Johns Hopkins University Press for Resources for the future, 1977), p. 150-151. Reprinted by permission.

Table A.3

Variable	Description	1969 (69 SMSAs) Mean	Standard deviation
Air Pollution	Min S: Smallest biweekly sulfate reading (μg per cubic meter × 10)	34.768	18.608
	Mean S: Arithmetic mean of biweekly sulfate readings (μg per cubic meter × 10)	115.652	47.258
	Max S: Largest biweekly sulfate reading (μg per cubic meter × 10)	286.435	142.852
	Min P: Smallest biweekly suspended particulate reading (μg per cubic meter)	32.290	14.691
	Mean P: Arithmetic mean of biweekly suspended particulate readings (μg per cubic meter)	99.507	27.436
	Max P: Largest biweekly suspended particulate reading (μg per cubic meter)	268.768	149.779
	Min NO_3: smallest biweekly nitrate reading (μg per cubic meter × 10)	4.377	3.469
	Mean NO_3: arithmetic mean of biweekly nitrate readings (μg per cubic meter × 10)	21.609	11.774
	Max NO_3: largest biweekly nitrate reading (μg per cubic meter × 10)	61.667	36.029
	Min NO_2: smallest biweekly nitrogen dioxide reading (μg per cubic meter)	40.319	24.885
	Mean NO_2: arithmetic mean of biweekly nitrogen dioxide readings (μg per cubic meter)	136.232	53.882
	Max NO_2: largest biweekly nitrogen dioxide reading (μg per cubic meter)	281.667	119.704
	Min SO_2: smallest biweekly sulfur dioxide reading (μg per cubic meter)	4.536	3.592
	Mean SO_2: arithmetic mean of biweekly sulfur dioxide readings (μg per cubic meter)	33.000	29.355
	Max SO_2: largest biweekly sulfur dioxide reading (μg per cubic meter)	115.812	97.608
Socioeconomic	P/M²: SMSA population density (per square mile × 0.1)	97.813	160.781
	≥65: Percentage of SMSA population at least sixty-five years old (×10)	90.913	20.487
	NW: Percentage of nonwhites in SMSA population (×10)	129.609	92.209
	Poor: Percentage of SMSA families with incomes below the poverty level (×10)	87.899	35.103
	Log Pop: The logarithm of SMSA population (×100)	586.181	35.907
Mortality	Unadjusted total mortality rate (per 100,000)	910.058	138.238
	Age-sex-race-adjusted total mortality rate (per 100,000)	959.812	71.094

Source: Lester B. Lave and Eugene P. Seskin, Air Pollution and Human Health (Baltimore: Johns Hopkins University Press for Resources for the Future, 1977), pp. 323, 336. Reprinted by permission.

change in mortality associated with a one percent change in ambient sulfur dioxide or

$$\frac{\frac{\Delta M}{M}}{\frac{\Delta SO_2}{SO_2}} = \eta \rightarrow \frac{\Delta M}{\Delta SO_2} = \eta \frac{M}{SO_2} \qquad \text{A.1}$$

where: M = mean mortality rate

SO_2= mean sulfur dioxide reading

n = elasticity.

To convert the elasticity to a linear coefficient the known values (see Table A.3) can be substituted into the expression on the right. For the unadjusted linear coefficient, the derivation is as follows:

$$\Delta M = .0366 \left(\frac{910.058}{33.000}\right) = 1.01 \qquad \text{A.2}$$

A similar procedure, using the adjusted elasticity (.0232) and mortality rate (959.812), results in a low coefficient of .65. These coefficients represent the unit change (rather than percent) in mortality per one ug/m^3 (rathern than one percent) in ambient sulfur dioxide. The implications of the alternative, constant elasticities, is discussed in the text.

Calculation of the unadjusted Montana mortality rate is straight-forward. An average of 1969, 1970, and 1971 mortality per 100,000 1970 population is 968.160.[2] The calculation of an

[2]Mortality figures are derived from Vital Statistics, published annually; the population was obtained from the 1970 Census of Population.

adjusted mortality rate is slightly more complicated. It is described in detail in the appendices to Lave and Seskin (1977). The Montana mortality rate is calculated (again a 1969, 1970, and 1971 average) for each of nine age groups[3] for both white and nonwhite population.[4] These 18 mortality rates were then weighed by percent make-up of the national population. The resulting age-race adjusted Montana mortality rate is 981.34, # slightly more than the unadjusted rate. This is primarily due to Montana's relatively small nonwhite population. The age-race adjusted mortality rate corresponds to what Montana's mortality rate would be if its population had the demographic characteristics of the national average.

Since the linear coefficients derived above estimate the unit change in mortality, the effect of using the age-race adjusted mortality would be to slightly reduce the resulting percent reduction. Thus the downward effect of the adjusted mortality corresponds to the downward effect of using the adjusted coefficient. These two factors together are used to generate the low estimate. The unadjusted mortality is used with the unadjusted coefficient for the high estimate.

---

[3] < 5, 5-14, 15-25, 25-34, 35-44, 45-54, 55-64, 65-74, ≥ 75.

[4] An inspection of sex proportions in Montana revealed little deviation from the national averabes.

APPENDIX B

VEGETATION DAMAGE CLASS MODIFICATION

This appendix explains the rationale for modifying the SRI crop damage classes. Based on the scientific literature, the SRI analysis grouped crops into damage classes on a scale of A to E with A representing crops whose economic portion was highly susceptible to sulfur dioxide fumigations. A damage class of E was given to those crops with economic portions highly resistant to sulfur dioxide.

These damage classes require modifications to reflect knowledge put forth by recent publications. Of the eight crops examined, alfalfa and sugar beets remain in the damage classes designated by SRI. The remainder, barley, beans, hay, oats, timber, and wheat, were modified as follows:

Crop	SRI damage Class	Modification
Barley	C	B
Beans	C	B
Hay	E	C
Oats	C	B
Timber	C	A
Wheat	C	A

The rationale behind the modification is twofold: (1) the scientific literature published since the original SRI analysis documented higher levels of sensitivity of these crops and (2) the SRI damage classes are relative classifications, e.g., if alfalfa was given an A classification and the literature suggested

that wheat was as sensitive or more sensitive to sulfur dioxide, wheat was modified to an A classification.

Among the papers published was that of Guderian (1977) who reported that, at ambient concentrations of approximately 40 ug/m^3 sulfur dioxide averaged over the growing season, wheat suffered a 15 percent yield loss. In another important experiment, Materna (1973) found that, at average annual concentrations of 20 to 24 $\mu g/m^3$, fir forests experienced a 20 percent loss in growth. He also found that concentrations of 70 to 100 ug/m^3 resulted in the rapid death of whole groups of trees. Based on this evidence the damage classes wheat and timber were modified to class A, the same as alfalfa.

Guderian (1977) also found that, at sulfur dioxide concentrations of approximately 25 ug/m^3 averaged over the growing season, oats showed leaf injury. The EPA (1973) in its reevaluation of sulfur dioxide criteria, rated barley and beans as relatively sensitive to sulfur oxides. It was felt that a C ranking, that of relatively resistant crops such as sugar beets, was not appropriate for oats, barley, and beans which subsequently were given damage class B ratings.

The original SRI analysis classified hay as an E crop, totally resistant to any concentration of sulfur dioxide. A multitude of evidence (e.g., Wilhour et al. 1978 and EPA 1978a) suggests that rye grass and alfalfa are highly sensitive to ambient sulfur dioxide. Hay (which is often a mixture of these and other plants) was given a damage class of C based on this evidence.

An additional factor in the original SRI damage class designation warrants discussion. As previously mentioned, the SRI damage class designations were based not only on the susceptibility of the whole plant, but on the susceptibility of the economic portion of the plant, e.g., a plant that was found to be highly sensitive to sulfur dioxide, but whose economic portion was relatively resistant, was given a damage class ranking of C. The question is, what is the economic portion of a plant? A review of the SRI analysis reveals that the economic portion is construed to mean the portion harvestable, marketable, eatable, or otherwise desired. This definition of "economic portion" is, indeed, incomplete because of its focus on acute effects. Non-economic portions of the plant, such as roots and leaves, make an important contribution to the vitality of the plant and damage to these portions of the plant has longer term economic effects through reduced yields.

100 copies of this publication were produced at a unit cost of $1.46 per copy, for a total cost of $ 253.55 which includes $ 146.45 for printing and $107.10 for distribution.